

# **Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-106**

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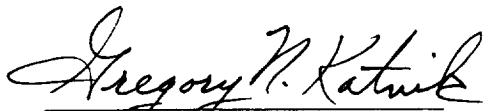
**DEBRIS/ICE/TPS ASSESSMENT  
AND  
INTEGRATED PHOTOGRAPHIC ANALYSIS  
OF  
SHUTTLE MISSION STS-106**

**8 September 2000**

Contributions By:

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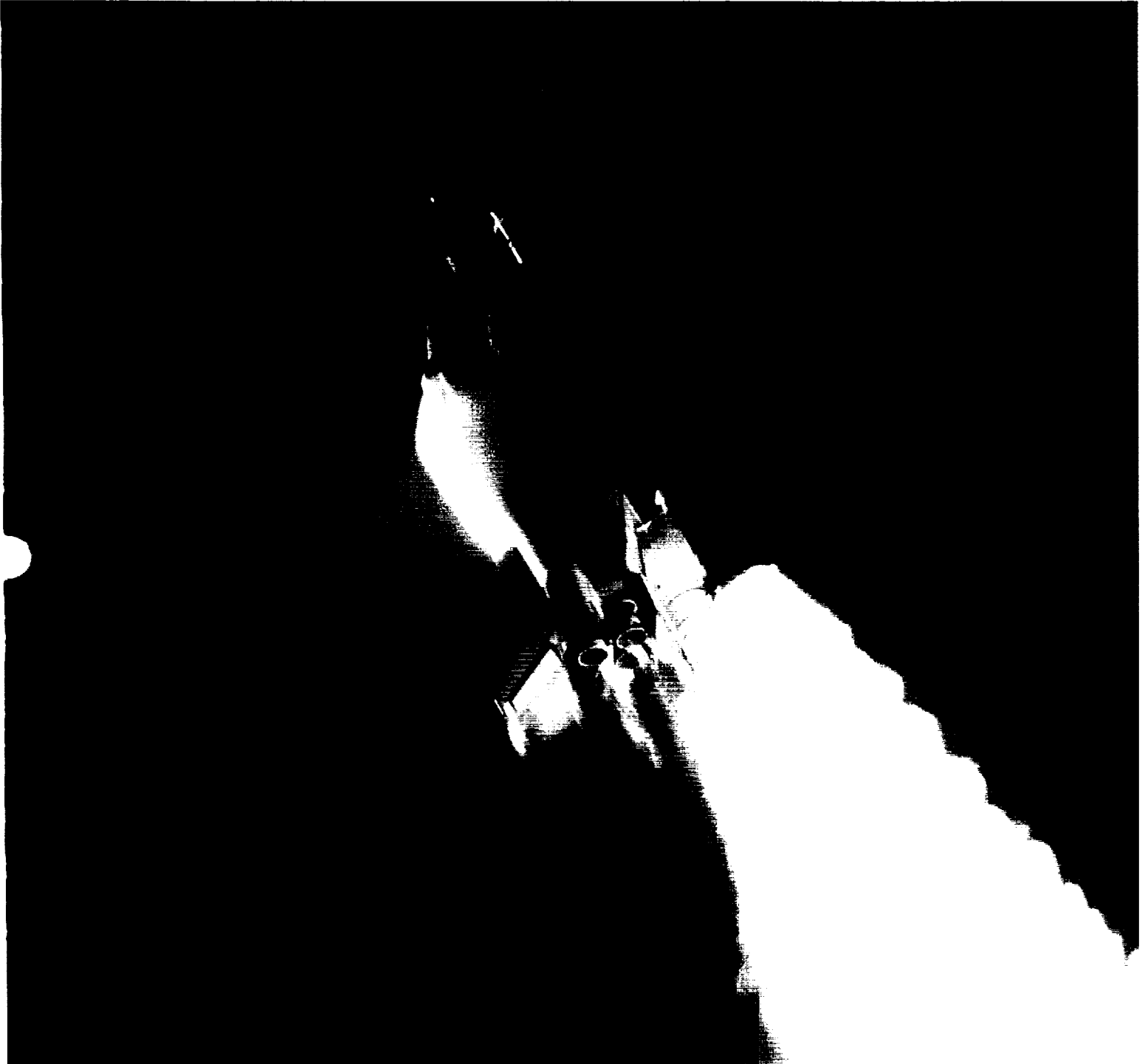
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**Photo 1: Launch of Shuttle Mission STS-106**

## **1.0 SUMMARY OF SIGNIFICANT EVENTS**

STS-106 consisted of OV-104 Atlantis (22nd flight), ET-103, and BI-102 SRB's on MLP-2 and Pad 39B. Atlantis was launched at 12:45:47.025 UTC (8:45 a.m. local) on 8 September 2000. Landing was at 3:56 a.m. local/eastern time on 20 September 2000.

### **GN2 Purge Lines**

Both SRB aft skirt GN2 purge lines were damaged. The LH side was severed and found on the haunch near the base of holddown post #6. The RH side purge line was broken but remained attached by the flex line braided shield. No protective tape remained on either purge flex line. The condition of the lines was an unexpected finding since corrective action had been taken after the failure (severance) of both purge lines on the STS-87 launch. The corrective action consisted of wrapping each line with three layers of blast tape for added thermal protection. Corrective action for STS-92 will consist of wrapping each line with six layers of metallic tape rather than three layers used previously to prolong time the metal braid is protected from melting.

### **ET Separation Bolt**

The EO-3 separation bolt protruded from the ET ball fitting and cast a shadow on the LO2 ET/ORB umbilical. Normally, the sep bolt is recessed and not visible. However, its appearance is not considered an anomaly as long as the bolt is free floating in the bore and cannot react separation loads into either the Orbiter or ET.

### **ET TPS Divots in On-Orbit Photography**

Numerous divots occurred in the LH2 tank-to-intertank flange closeout. Three divots, approximately 4-6 inches in diameter, were located between the LO2 feedline and +Y thrust panel. Primed substrate was visible in two of the three divots. There is a possible divot in the flange closeout under the pressurization line itself. Three more divots, also averaging 4-6 inches in diameter, were located between the bipod struts. However, the bipod jack pad standoff closeouts were intact and in excellent condition.

Just forward of the flange closeout and almost on centerline with the bipods was a divot on the stringer head TPS estimated to be 8 inches long by 2 inches wide. Two small divots were visible on the stringer head TPS forward of the +Y bipod housing closeout in the intertank acreage.

Approximately 12 inches aft of the flange closeout/bipods were two shallow 2-inch diameter divots in the LH2 tank acreage.

The divots have been accepted by the Space Shuttle Program unless significant Orbiter tile damage occurs as a result of TPS debris impacts.

## 2.0 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 0730 on 7 September 2000. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

G. Katnik	NASA - KSC Shuttle Ice/Debris Systems
R. Speece	NASA - KSC Thermal Protection Systems
J. Rivera	NASA - KSC ET Mechanisms/Structures
W. Boyter	NASA - KSC SRB Mechanical Systems
B. Nguyen	NASA - KSC SRB Mechanical Systems
R. Page	NASA - KSC SSP Integration
K. Revay	USA - SFOC Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC ET Mechanical Systems
W. Richards	USA - SFOC ET Mechanical Systems
M. Wollam	USA - SFOC ET Mechanical Systems
T. Ford	USA - SFOC ET Mechanical Systems
R. Seale	USA - SFOC ET Mechanical Systems
R. Brewer	USA - SFOC ET Mechanical Systems
R. Oyer	Boeing Systems Integration
C. Hill	Boeing Systems Integration
D. Leggett	Boeing Systems Integration
E. Bissonnette	Boeing Systems Integration
M. Eastwood	THIO - LSS SRM Processing
S. Otto	LMMSS ET Processing
J. Ramirez	LMMSS ET Processing

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were present on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were normal.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a normal amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

#### **3.2.4 FACILITY**

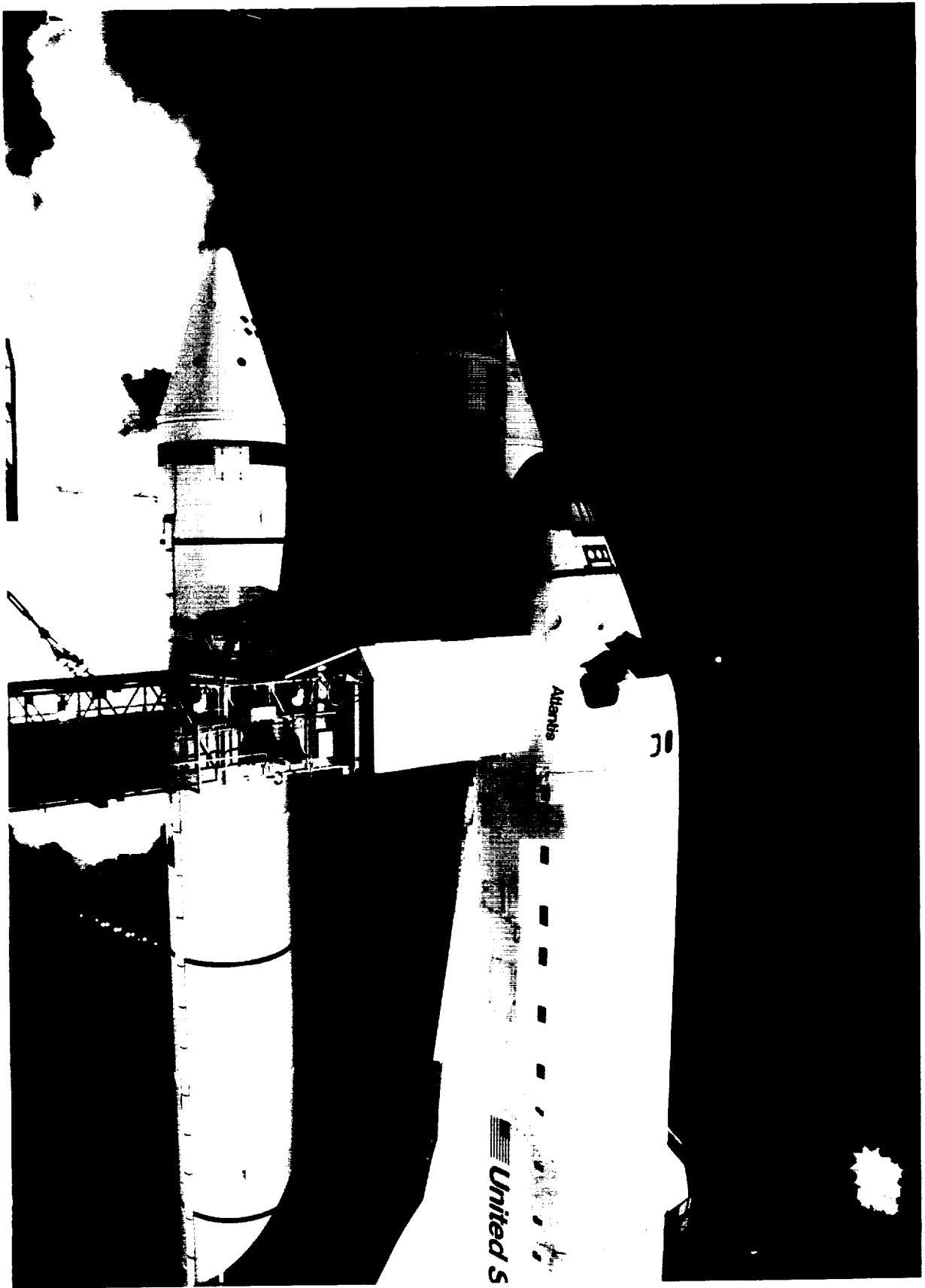
All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

#### **3.3 T-3 HOURS TO LAUNCH**

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing previously assessed did not increase. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some areas of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the "no-ice zone".

STS-106 was launched at 12:45:47.025 UTC (8:45 a.m. local) on 8 September 2000.





**Photo 2: ET LO2 Tank and Intertank**

The Final Inspection Team observed light condensate on the LO2 tank acreage. Surface temperatures ranged from 62 to 68 degrees F. There were no TPS anomalies. No significant anomalies were present in the intertank TPS and no cracks in stringer valley TPS were detected.



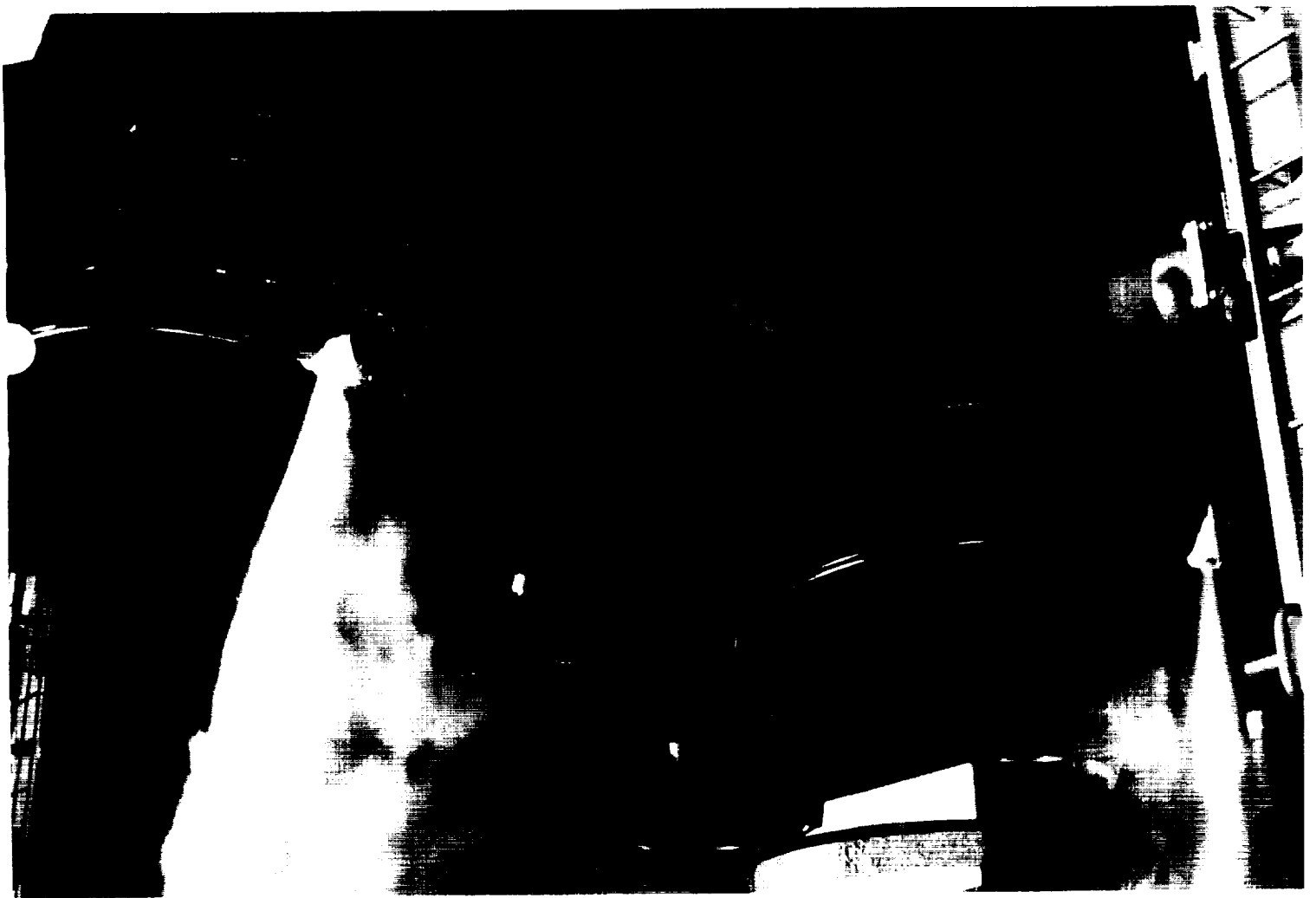
**Photo 3: LH2 Tank**

Light condensate was present on the LH2 tank acreage. Surface temperatures ranged from 58 to 62 degrees Fahrenheit. There were no acreage TPS anomalies. Although surface cracks had appeared in the +Y longeron closeout foam on the previous two ET's, no cracks were present at this location during this cryoloading.



**Photo 4: LH2 ET/ORB Umbilical**

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a normal amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents.



**Photo 5: Overall View of SSME's**

Ice/frost had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. Condensate was present on all three heat shields.

## 4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP-2, Pad B FSS and RSS was conducted on 8 September 2000 from Launch + 2 to 4 hours. No flight hardware was found.

A stud hang-up was not expected on this launch. Boeing-Huntington Beach reported an Orbiter liftoff lateral acceleration of 0.09 g's, which is below the threshold (0.14g's) for stud hang-ups. Visual inspection of both south post revealed no evidence of stud hang-ups. Erosion was typical for the south posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage.

Both SRB aft skirt GN2 purge lines were damaged. The LH side was severed and found on the haunch near the base of holddown post #6. The RH side purge line was broken but remained attached by the flex line braided shield. No protective tape remained on either purge flex line. The condition of the lines was an unexpected finding since corrective action had been taken after the failure (severance) of both purge lines on the STS-87 launch. The corrective action consisted of wrapping each line with three layers of blast tape for added thermal protection. Corrective action for STS-92 will consist of wrapping each line with six layers of metallic tape rather than three layers used previously to prolong time the metal braid is protected from melting.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the bonnets were closed properly. The MLP deck was in generally good shape. A stainless steel bolt and a pip pin were found on side 2 (West) of MLP surface. The RTV (rubberized) paint applied to camera and other exposed surfaces was relatively intact with minimal erosion.

The GH2 vent line latched in the six of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage. The vent line sustained more than usual plume impingement as indicated by the severe scorching of the 4-foot vacuum jacketed flex-hose, GUCP housing and electrical wiring. The GH2 vent line latching mechanism release lever was missing a pip pin. Several grating clamps were found loose adjacent to the vent line deceleration mechanism.

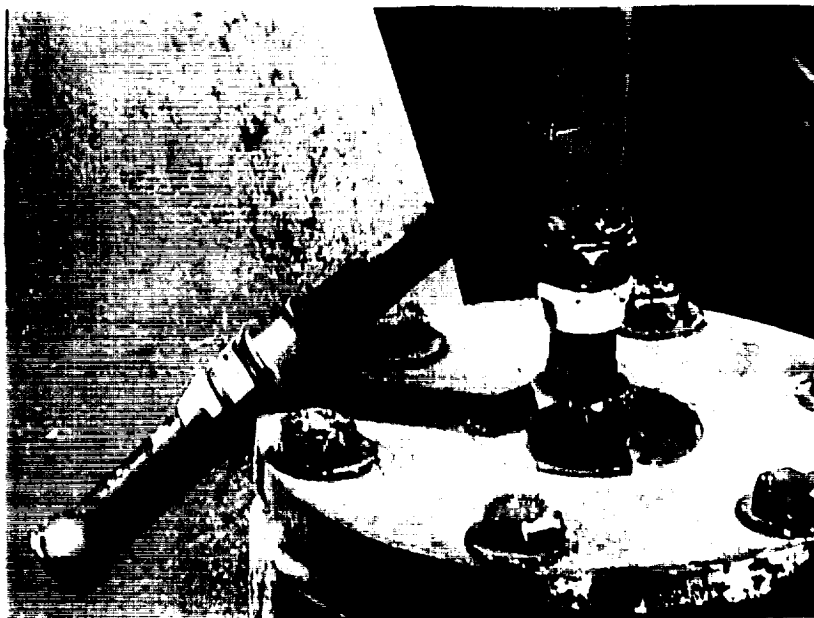
The OAA appeared to be intact with no evidence of plume impingement. Emergency egress basket #7 was found deployed and was at the landing site near the bunker.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings on the FSS included

- No significant damage was noted in the flame trenches. No flight debris was found on the pad acreage.
- A 12-inch x 6-inch aluminum flashing material was found in the south flame trench.
- 95 foot level- Hand rail on the east side was broken
- 155 foot level- Electrical box on north side of FSS had broken latches.
- Several pip pins were damaged or had broken tethers throughout the FSS.

Overall, damage to the pad appeared to be minimal.



**Photo 6: Aft Skirt GN2 Purge Lines**

Both SRB aft skirt GN2 purge lines were damaged. The LH side was severed and found on the haunch near the base of holddown post #6. The RH side purge line was broken but remained attached by the flex line braided shield. No protective tape remained on either purge flex line. The condition of the lines was an unexpected finding since corrective action had been taken after the failure (severance) of both purge lines on the STS-87 launch.

## 5.0 FILM REVIEW

Anomalies observed in the Film Review were reported to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review.

### 5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 81 films and videos, which included twenty-eight 16mm films, seventeen 35mm films, and thirty-six videos, were reviewed starting on launch day.

Frost, but no ice, formed on the ET louvers after GOX vent seal retraction.

SSME ignition was normal with Mach diamonds appearing in a proper 3-2-1 sequence (OTV 151, 170, 171; E-52, -76, -77). Three flashes occurred in the SSME #1 plume during start-up. A piece of ice from the LO2 T-0 umbilical carrier plate fell and impacted SSME #3 nozzle 12:45:45.03 UTC, but no damage was visible (E-2, -3, -17, -19, -20).

A large, white, square looking object believed to be a piece of ice from the LO2 T-0 purge box fell aft past SSME #3 and #1 during ignition without impacting flight hardware (OTV 170).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no tile damage was visible.

Less than usual amount of free burning hydrogen was visible in the orbiter base heat shield area and vertical stabilizer root.

Although not an anomaly, it was unusual for two aft RCS thruster paper covers to remain intact during SSME start-up (OTV 150).

Small pieces of tile surface coating material were lost during ignition from three places on the base heat shield, five places on the SSME #3 engine heat shield, and three places on the -Y OMS engine heat shield (E-18, -19, -20).

A thin, light-colored debris object, estimated to be 2-3 inches in length, appeared in the left field of view at 45:43.665 UTC and fell into the SRB exhaust hole near HDP #3 rather than drawn toward the Orbiter by aspiration (E-10).

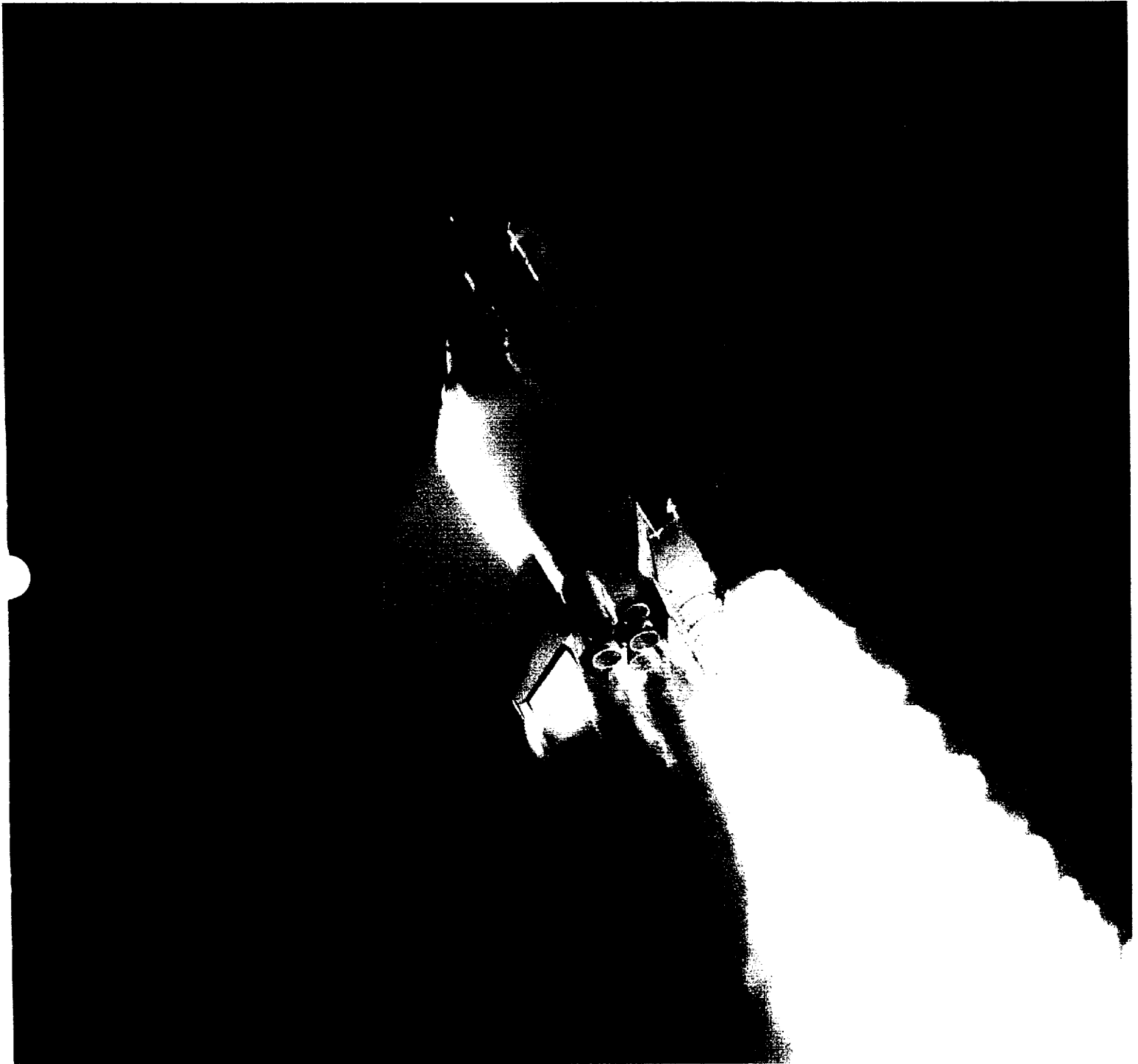
Two unidentified, small, dark-colored debris objects entered the field of view from above the Orbiter left wing falling downward at 45:44.528 UTC. No contact with the flight hardware was observed (E-3).

Water leaked from the sound suppression water pipe near HDP #4 (E-7, -10, -11).

No holddown post stud hang-ups occurred on this launch. No debris/ordnance fragments fell from the SRB aft skirt stud holes (E7-14).

The GN2 purge lines separated cleanly from both SRB aft skirts at liftoff. The purge lines were visible for about two seconds after T-0. No anomalies were observed at this time. However, the post launch pad inspection later found the RH purge line hanging by a few metal wire strands while the LH purge line was completely severed and lying on the HDP #6 haunch (E-8, -13).

GUCP disconnect from the ET was normal. There was no TPS damage (E-33).



**Photo 7: Atlantis at Mach Speed**

Combination of atmospheric conditions and shock wave condensation collars  
backlit by the sun provided a unique image of Atlantis during ascent



## **5.3 ON-ORBIT FILM AND VIDEO SUMMARY**

### **5.3.1 16mm Film Footage**

OV-104 was equipped to carry ET/ORB umbilical cameras: 16mm motion picture with 5mm lens and 16mm motion picture with 10mm lens from the LH2 side; 35mm still views from the LO2 side. The film (FL102) did not run in the 16mm camera with the 10mm lens.

Illumination from the SRB exhaust plumes showed typical ablation/erosion/flaking of thin layers of TPS from the aft surfaces of the -Y upper strut fairing, -Y vertical strut, and LH2 ET/ORB cable tray. TPS charring and "popcorn" divoting of the aft dome was also typical.

SRB separation from the External Tank appeared nominal. The wide angle ET/ORB LH2 umbilical camera provided a view of the left SRB falling away from the ET. Ablator and topcoat on the forward skirt/frustum was intact and no material was missing.

ET separation from the Orbiter also appeared nominal. No damage was detected on the LH2 ET/ORB umbilical. Frozen hydrogen adhered to the 17-inch disconnect. Ice was present on the LH2 tank acreage at the transportation fitting, as expected. The red colored purge seal around the EO-2 ball fitting was in place.

No unusual TPS erosion or debris impacts were noted on the -Y thrust strut.

Light colored spots on and near the LH2 tank-to-intertank flange closeout may be divots and will be verified in the 35mm film.

### **5.3.2 35mm Film Footage**

A total of 57 still images from the LO2 ET/ORB 35mm umbilical camera of the External Tank after separation from the Orbiter were received. All images were in clear focus with excellent lighting. The +X translation had been performed giving an exceptionally good view of the bipod and nose cone areas.

The EO-3 separation bolt protruded from the ET ball fitting and cast a shadow on the ET/O LO2 umbilical. Normally, the sep bolt is recessed and not visible. However, its appearance is not considered an anomaly as long as the bolt is free floating in the bore and cannot react separation loads into either the Orbiter or ET. The red-colored purge seal that normally fits around the EO-3 ball fitting had come loose and floated aft still held by the tether (though it later drifted back into near proper position in the zero-g environment).

No damage was detected on the LO2 ET/ORB umbilical disconnect, sealing surfaces, or closeout TPS. Typical ablation and divoting was noted on the vertical portion of the umbilical cable tray.

ET LH2 tank +Y+Z acreage appeared nominal. As expected, small divoting and "popcorning" of the TPS occurred on the aft dome and aft portion of the LH2 tank.

Ablation/erosion of LO2 feedline and thrust strut flange foam closeouts was typical. Ice was still present in the LO2 feedline aft bellows.

A small divot on the +Y thrust strut knuckle appeared to be the result of a debris impact.

The small, irregular, white or light-colored object floating in frames 13-30 field of view is believed to be a piece of frozen oxygen or hydrogen.



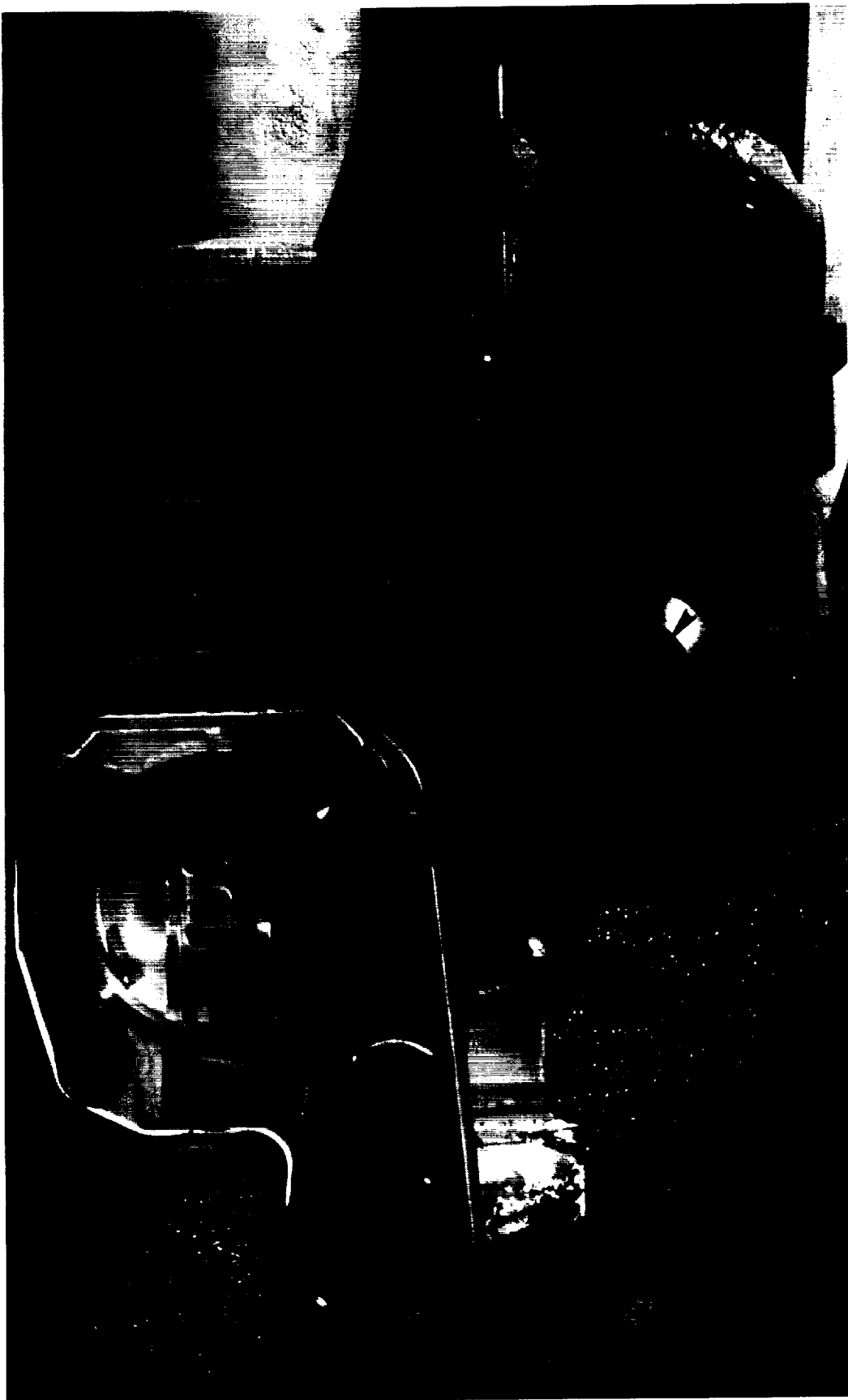
**Photo 8: SRB Separation from External Tank**

SRB separation from the External Tank was normal. Forward skirt/frustum ablator and topcoat was intact with no missing material. Note typical erosion of TPS from the ET/ORB umbilical cable tray.



**Photo 9: ET Separation from Orbiter**

View of External Tank shortly after separation from the Orbiter. No damage was detected on the LH2 ET/ORB umbilical. Note frozen hydrogen in the 17-inch disconnect. TPS acreage on the LH2 tank aft barrel section was in good condition. Note small piece of ice or frozen hydrogen floating near the TPS and casting a shadow.



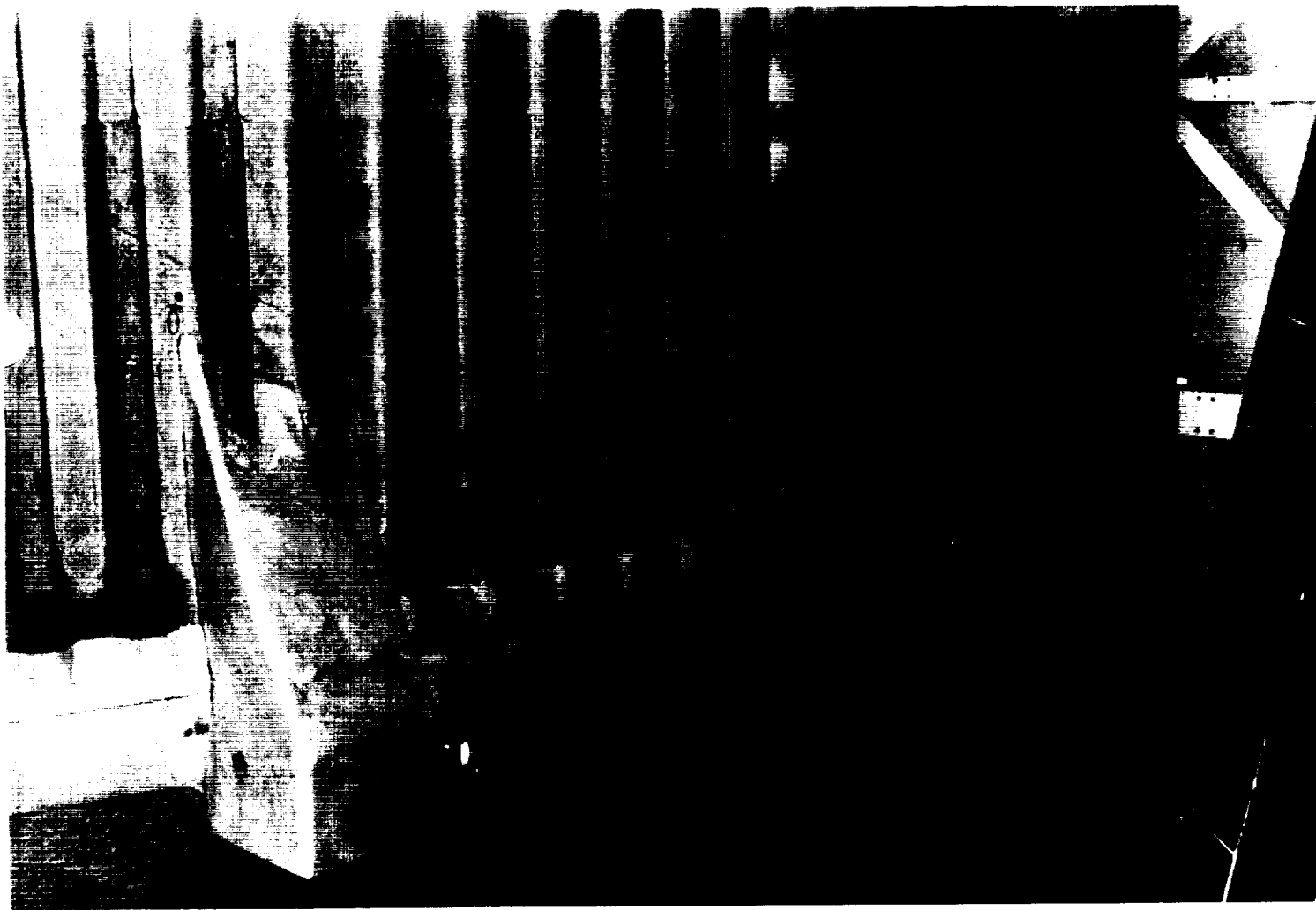
**Photo 10: ET Sep Bolt Protrusion**

The EO-3 separation bolt protruded from the ET ball fitting and cast a shadow on the ET/ORB LO2 umbilical. Normally, the sep bolt is recessed and not visible. However, its appearance is not considered an anomaly as long as the bolt is free floating in the bore and cannot react separation loads into either the Orbiter or ET. The red-colored purge seal that normally fits around the EO-3 ball fitting had come loose and floated aft still held by the tether.

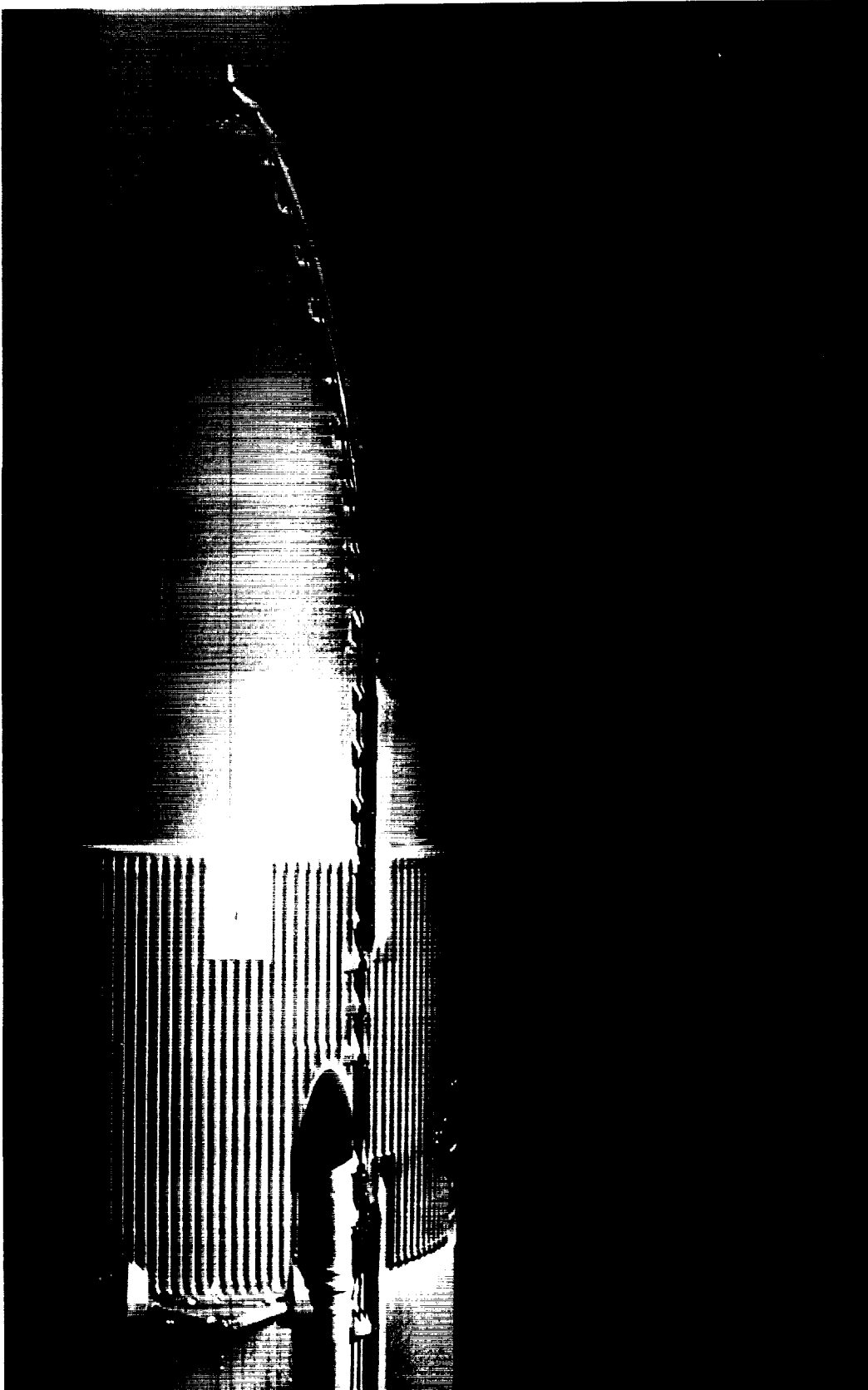


**Photo 11: ET TPS Erosion**

Erosion of TPS from the LO2 feedline and thrust strut flanges was typical. Very small devoting, or "popcorning", of the TPS on the LH2 tank was normal. Erosion of TPS from the ET/ORB LO2 umbilical cable tray was also typical. No damage was detected on the LO2 umbilical. Note: ice was still present in the LO2 feedline aft bellows and the small portion missing (arrow) was lost sometime during ascent.

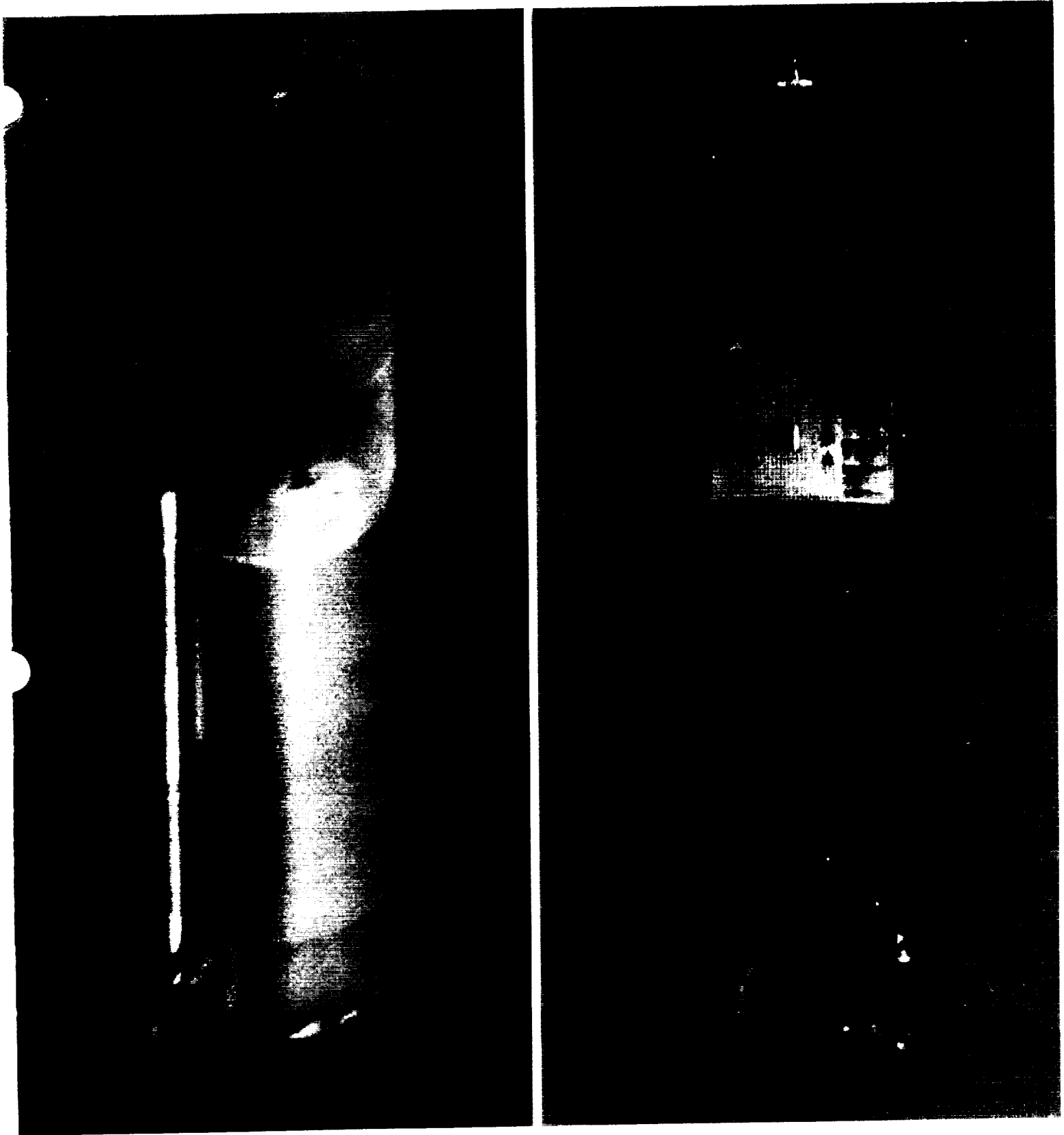


**Photo 12: ET Bipod Area Pre-Launch**



**Photo 13: ET Intertank And Nose Cone**

Numerous divots can be seen in the LH2 tank-to-intertank flange closeout to the +Y side of the PAL ramp and in between the bipods (Note: the jack pad stand off closeouts are intact), in the LH2 tank acreage near the flange, and from an intertank stringer head near the flange. Also, four small divots were present in the intertank acreage near the +Y thrust panel. TPS erosion and possible devoting has occurred on the upper ogive near the nose cone.



**Photo 14: ET Thrust Panels**

Both +Y and -Y intertank thrust panels exhibited no large divots (5-inches in diameter or greater). Smaller divots could not be discerned due to the subject distance and resolution. No anomalies were detected on the composite nose cone. Loss of topcoat and erosion of foam in the forward ogive sanded area was visible, but the presence of divots could not be confirmed.



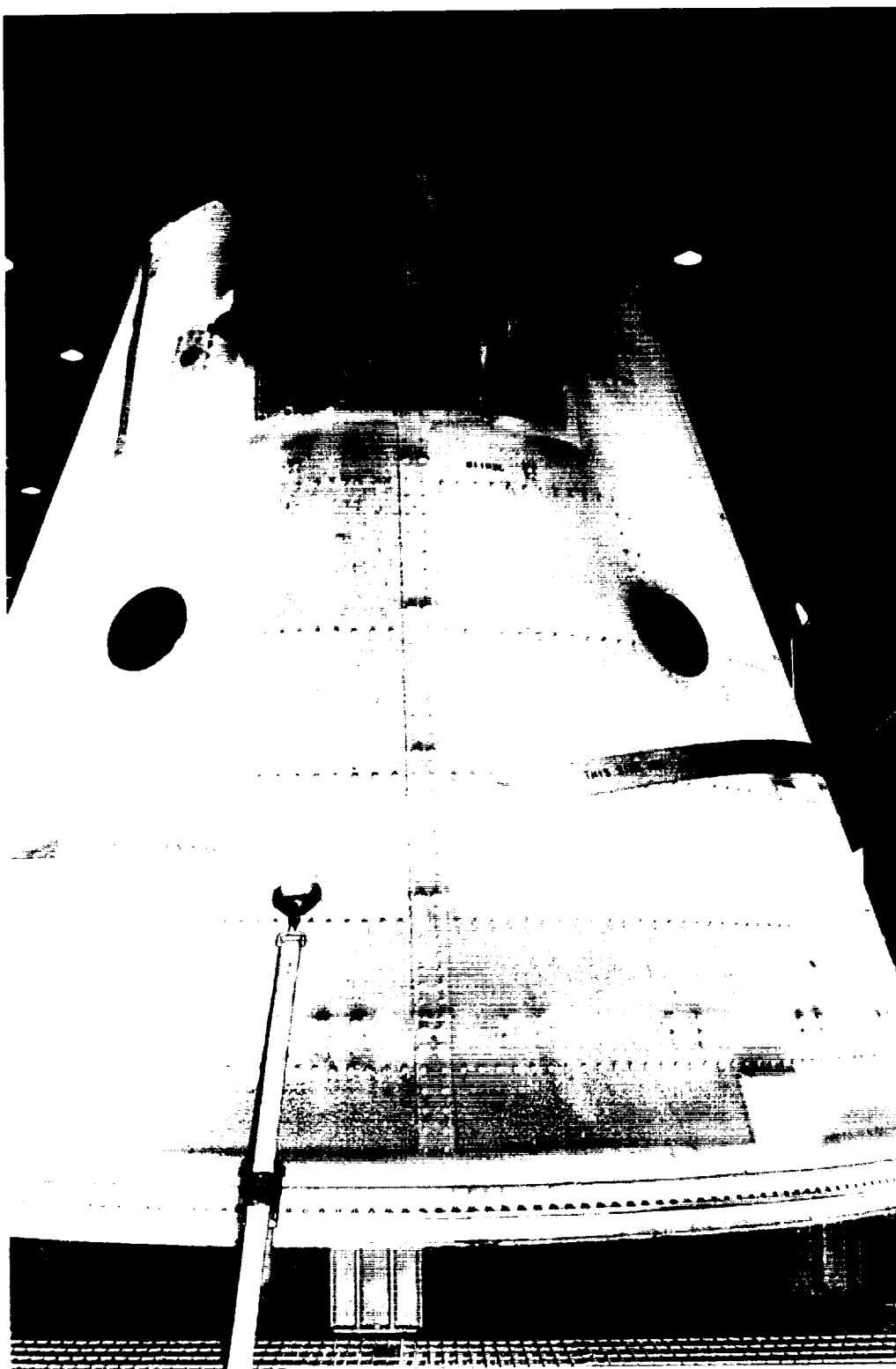
## **6.4 LANDING FILM AND VIDEO SUMMARY**

A total of 16 films and videos, which included seven 35mm large format films and nine videos, were reviewed. There was not much detail for engineering assessment due to the dark conditions of a night landing.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach.

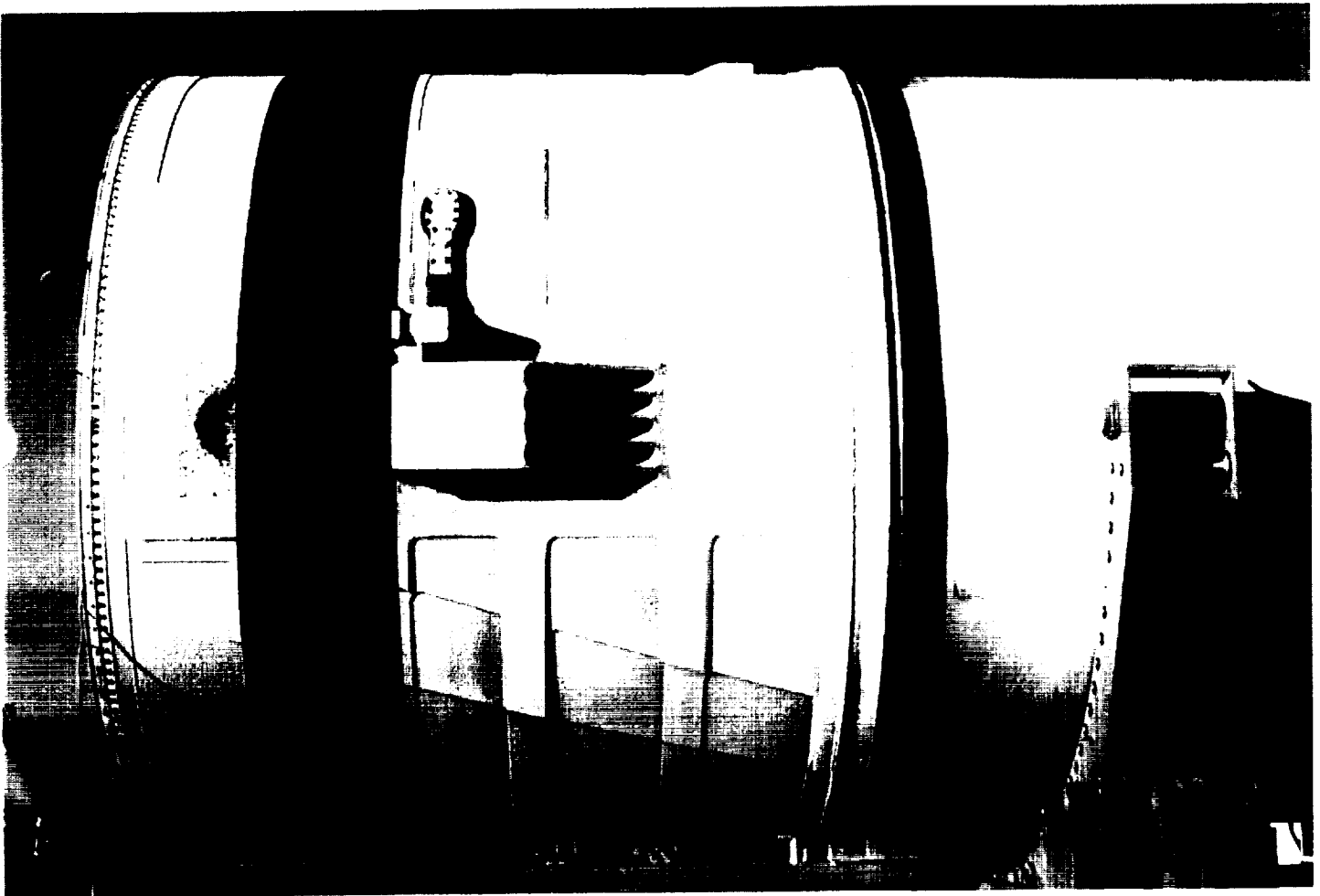
Runway centerline cameras showed right main landing gear contacting the runway first just to the east of the centerline markers.

Drag chute deployment, which occurred before the nose wheel contacted the runway, appeared normal. No anomalies were detected from touch down through rollout.



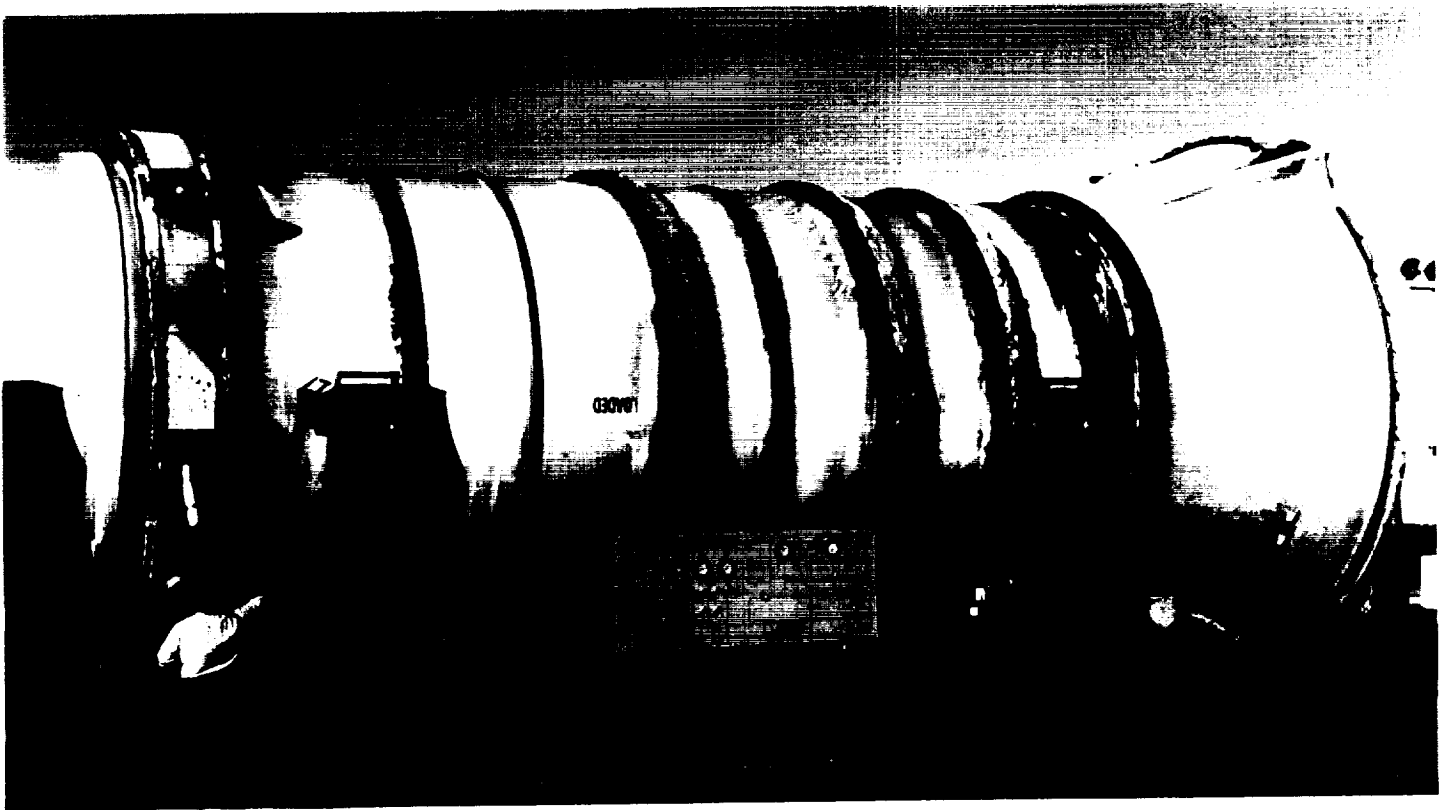
**Photo 15: Frustum Post Flight Condition**

The TPS on both frustums exhibited no debonds/unbonds. All eight BSM aero heat shield covers had fully opened at SRB separation as evidenced by cover contact marks on the nozzles. However, numerous covers and attach rings had been bent by parachute riser entanglement.



**Photo 16: Forward Skirt Post Flight Condition**

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact, though one layer of both +Z antenna base plates had delaminated. On the LH SRB frustum severance ring, a pin/retainer clip from the 310 degree location, a pin from the 48 degree location, and a pin/retainer clip from the 80 degree location were missing and believed to have been pulled loose by parachute riser entanglement.



**Photo 17: Aft Skirt Post Flight Condition**

Separation of the aft ET/SRB struts appeared normal. Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation closeouts.



**Photo 18: Obstructed DCS Plunger**

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally. However, the #5 and #8 plungers were not fully seated and were obstructed by frangible nut pieces, a condition that most likely occurred as the result of water impact (post launch film review showed no debris objects/ordnance fragments falling from the aft skirt stud holes during liftoff). There was no new broaching of stud holes. No stud hang-ups had been expected due to the lateral acceleration value of 0.09 g's.

## 7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 3:56 a.m. local/eastern time landing on 20 September 2000, a post landing inspection of OV-104 Atlantis was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 3. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 105 hits, of which 17 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. Of special note is the absence of tile damage from debris hits on the leading edge of the vertical stabilizer. Although hits were recorded on the window perimeter tiles and OMS pod leading edges, no damage sites larger than 1-inch in length were present (reference Figures 1-4).

The following table lists the STS-106 Orbiter debris damage hits by area:

	<u>HITS &gt; 1-inch</u>	<u>TOTAL HITS</u>
Lower surface	17	73
Upper surface	0	0
Window Area	0	16
Right side	0	4
Left side	0	1
Right OMS Pod	0	5
Left OMS Pod	0	6
TOTALS	17	105

The Orbiter lower surface sustained 73 total hits, of which 17 had a major dimension of 1-inch or larger. Approximately 20 damage sites (with five larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells on both left and right chines consistent with the loss of foam from the ET thrust panels. The quantity and average size of the damage sites compared to previous flights were considerably reduced as a result of the pre-launch TPS venting modification. And some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. In general, the lower surface tile damage on this flight is considered much improved.

Numerous tile damage sites around the ET/ORB umbilicals were most likely caused by umbilical ice or pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

The largest lower surface tile damage site, located on the right wing outboard of the main landing gear door, measured 6-inches long by 0.50-inch wide by 0.50-inch deep and affected three tiles. A 3-inch long by 0.38-inch wide by 0.38-inch deep damage site was located generally aft of this location on the right inboard elevon. The cause of both damage sites is believed to be ice from the ET LO2 feedline.

The landing gear tires were in good condition for a landing on the KSC concrete runway. There was no ply under cutting on the main landing gear tires.

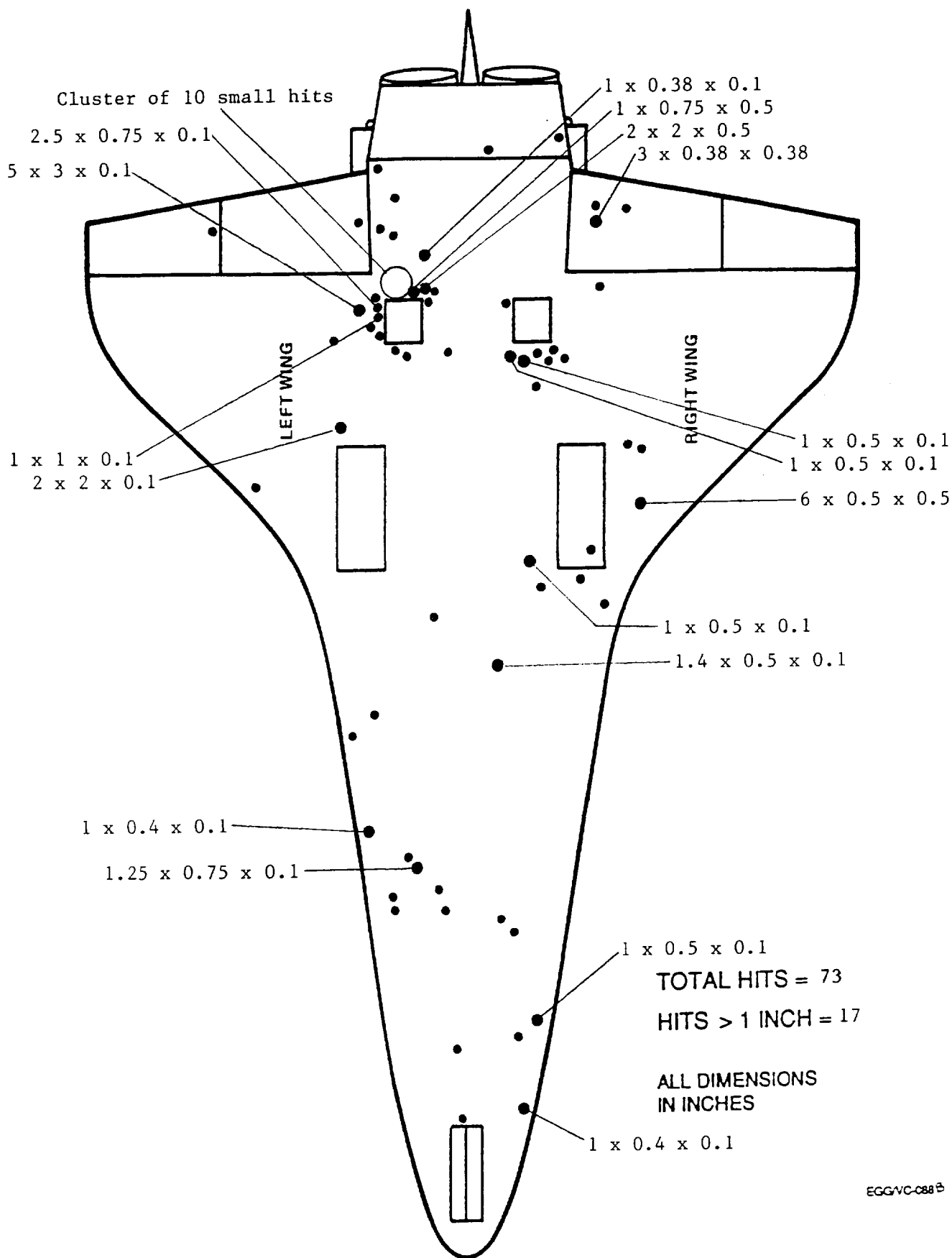
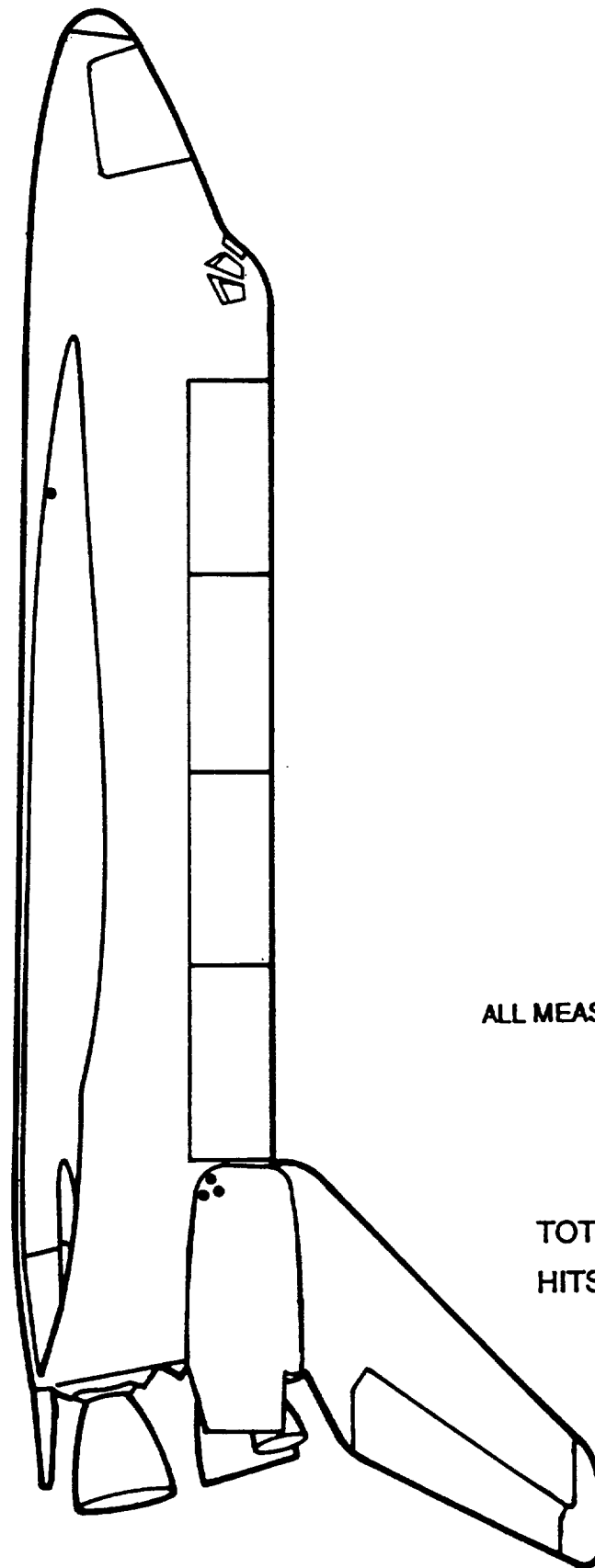


Figure 1: Orbiter Lower Surface Debris Damage Map



ALL MEASUREMENTS IN INCHES

TOTAL HITS = 4

HITS > 1 INCH = 0

EGG/VC-088

Figure 3: Orbiter Left Side Debris Damage Map



STS NUMBER	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
STS-99	21	75	25	88
STS-101	19	70	27	113
AVERAGE	11.3	60.5	16.1	102.6
SIGMA	6.1	34.7	6.5	30.8
STS-106	17	73	17	105

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

**Figure 5: Orbiter Post Flight Debris Damage Summary**

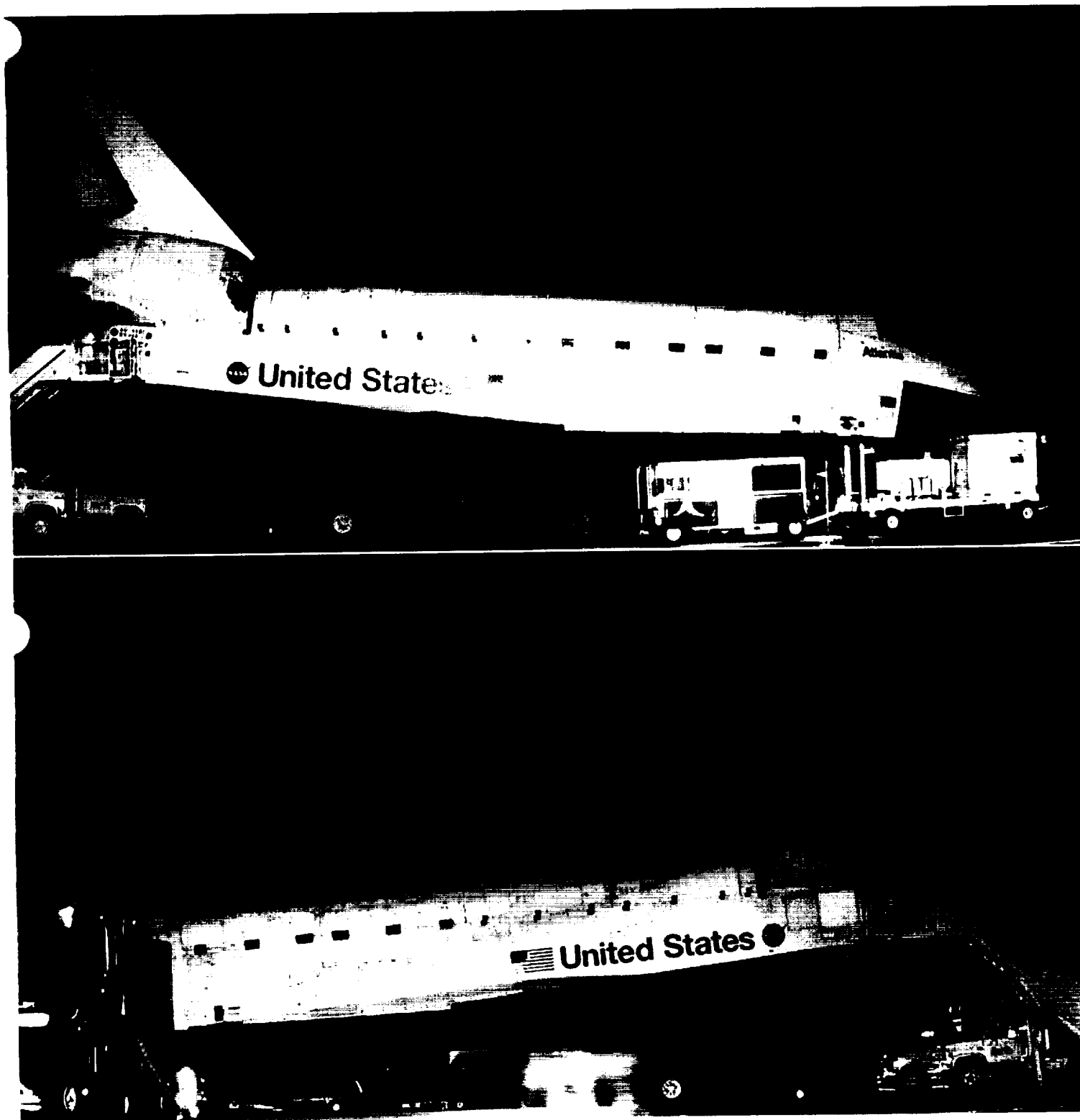
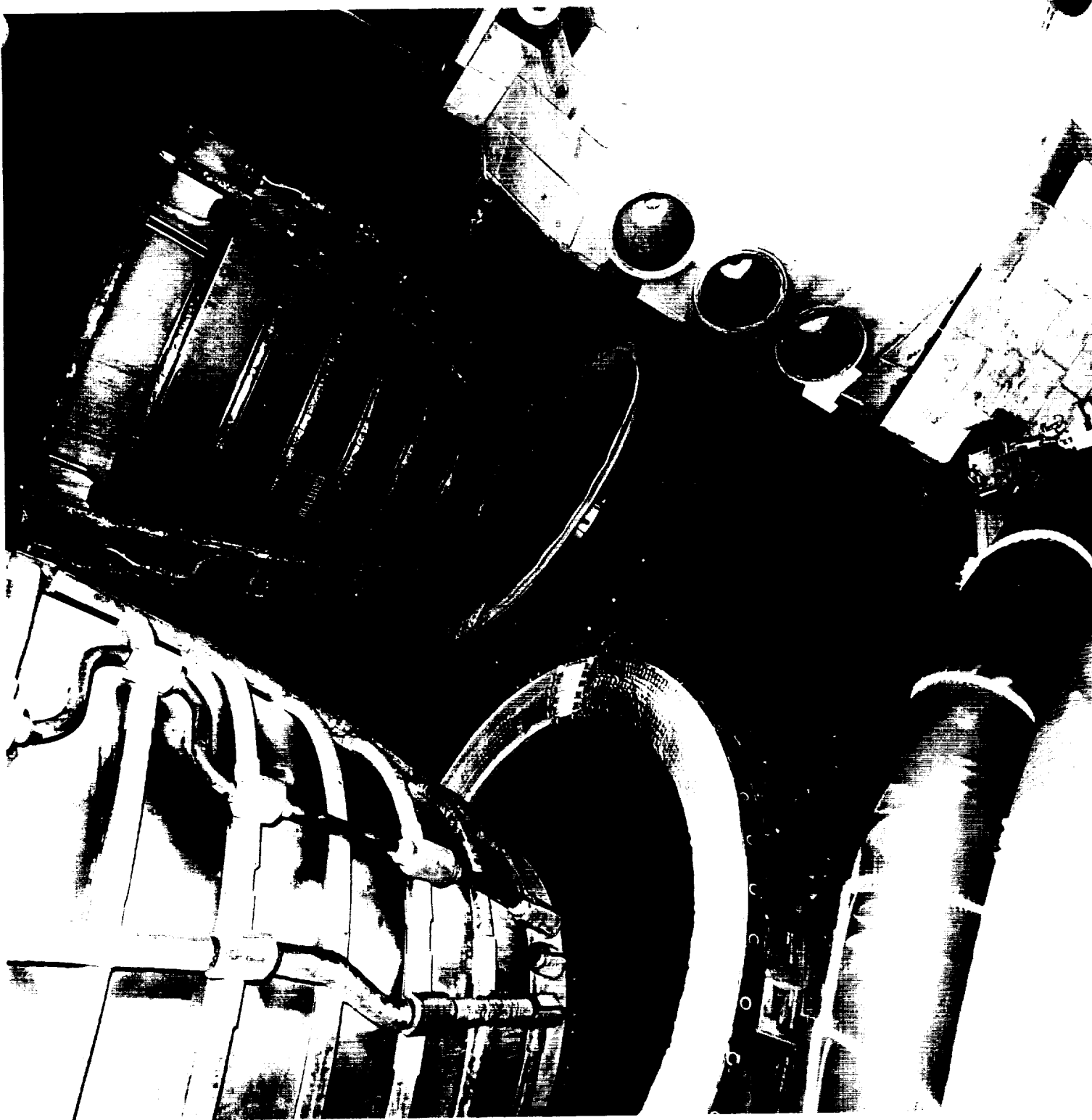


Photo 19: Overall View of Orbiter Sides



**Photo 20: Base Heat Shield**

Less than usual amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in excellent condition, though there was some slight fraying of the material on SSME #1 6:00 o'clock position and SSME #3 9:00 o'clock position.



**Photo 21: Damage to Lower Surface Tiles**

The Orbiter lower surface sustained 73 total hits, of which 17 had a major dimension of 1-inch or larger. The largest lower surface tile damage site, located on the right wing outboard of the main landing gear door, measured 6-inches long by 0.50-inch wide by 0.50-inch deep and affected three tiles. The damage cause is believed to be ice from the ET LO2 feedline.



**Photo 22: Lower Surface Tile Damage**

Numerous tile damage sites around the ET/ORB umbilicals were most likely caused by umbilical ice or pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

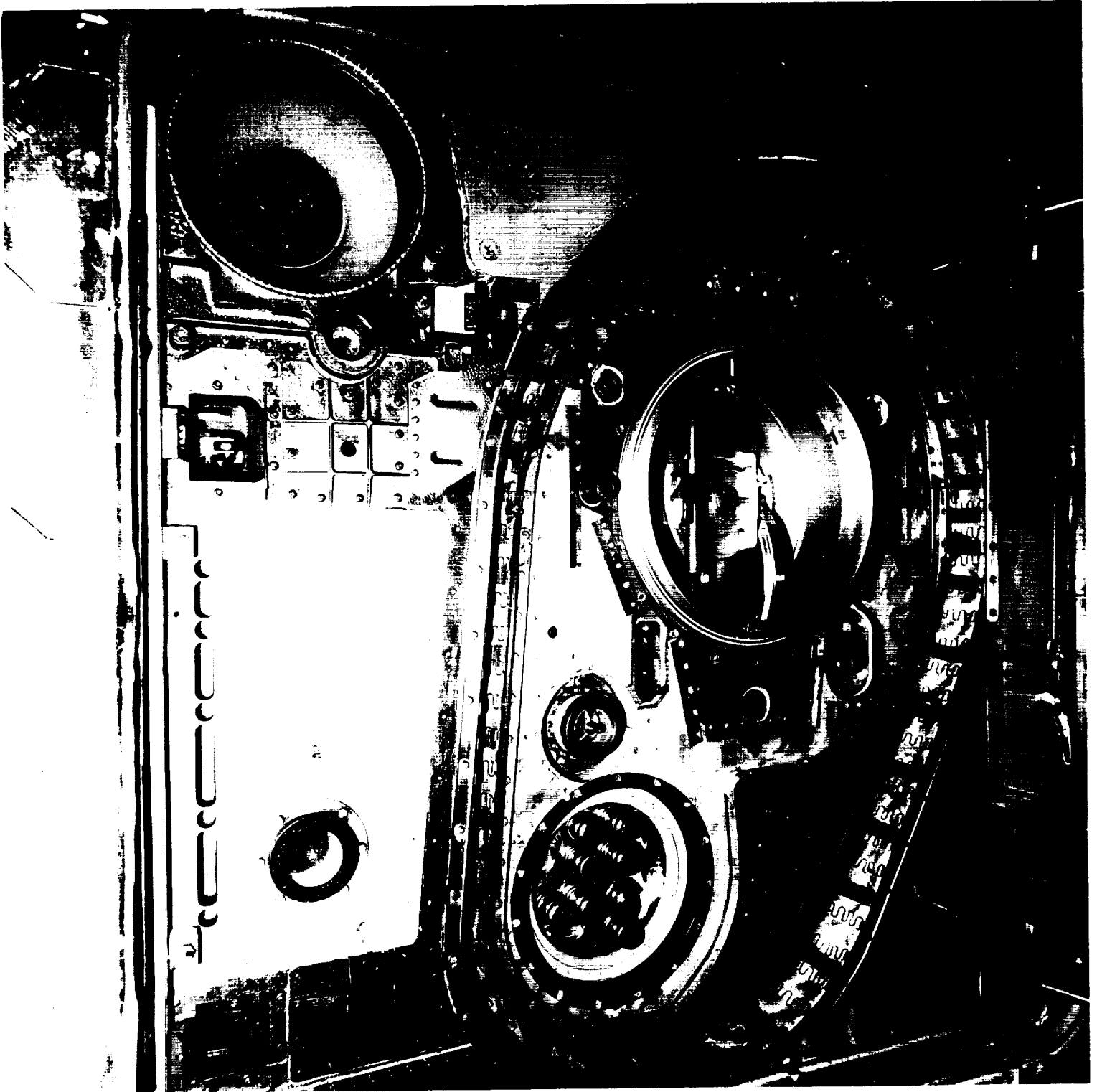


Photo 23: LO2 ET/ORB Umbilical

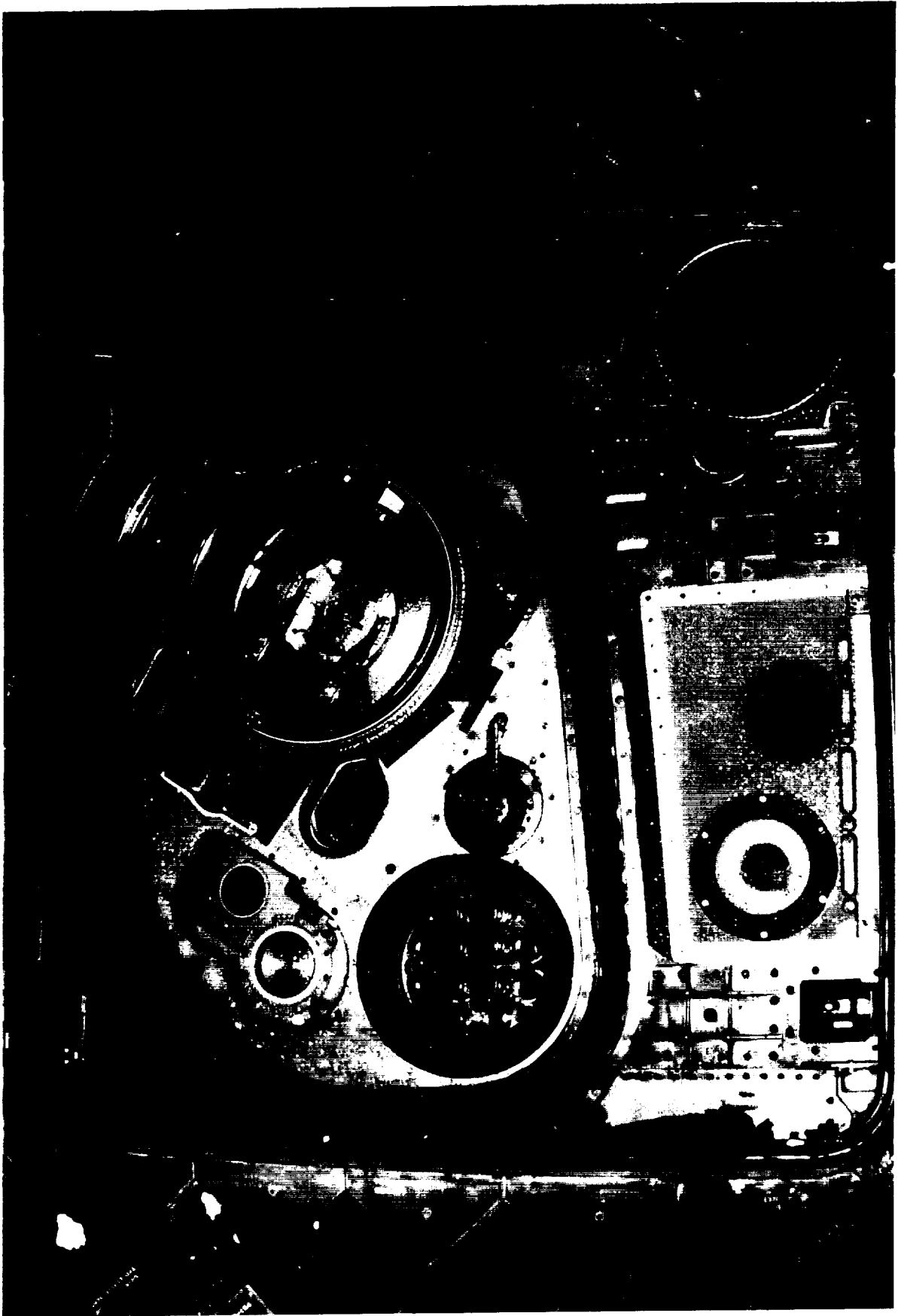


Photo 24: LH2 ET/ORB Umbilical



**Photo 25: Windows**

Damage sites on the window perimeter tiles were less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows was moderate.



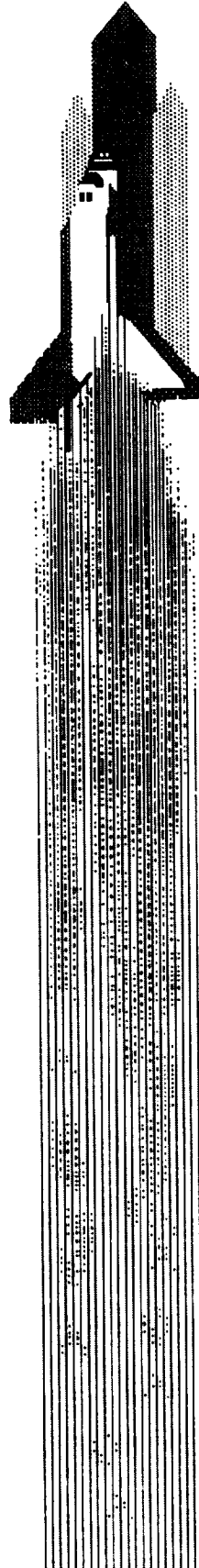
## **APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY**



## **Space Science Branch**

### **STS-106 Summary of Significant Events**

**November 10, 2000**





## Space Shuttle

# STS-106 Summary of Significant Events

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Project Work Order - SN3CT

### Approved By

Lockheed Martin

NASA

A handwritten signature in black ink, appearing to read "Jon Disler", is positioned above a horizontal line.

Jon Disler, Project Analyst  
Image Science and Analysis Group

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Robert W. Payne, Department Manager  
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### Prepared By

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Earth Sciences and Solar System Exploration Division  
Space and Life Sciences Directorate

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## **STS-106 (OV-104) Film/Video Screening and Timing Summary**

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Post landing, a sink rate analysis of the STS-106 main landing gear was performed for the main gear touchdown. See Section 2.7.

The drag chute deploy sequence appeared normal on the landing imagery. Venting from the APU vent located at the forward edge of the base of the vertical stabilizer was seen during the landing roll-out and after wheel stop. Venting from the APU during landing has occurred on previous missions.

According to the pre-mission agreement, the STS-106 landing films were not screened due to budgetary constraints.

### **1.1.4 Post Landing ET Protruding Bolt Investigation**

Support was provided to the NASA and contractor integration team that investigated the STS-106 External Tank (ET) aft EO fitting protruding separation bolt investigation. Umbilical well camera photography from the current and previous missions with protruded bolts was used to determine the bolt lengths above the attach fitting plane, bolt motions, retraction rates, and the time from ET separation when the bolts were first seen. Section 2.6 contains a description of the imagery analysis performed in support of this investigation.

## **1.2 LANDING EVENTS TIMING**

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 1.2.

## **Summary of Significant Events**

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### **2. SUMMARY OF SIGNIFICANT EVENTS**

#### **2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF**

Multiple pieces of ice debris and vapors were seen falling from the ET/Orbiter umbilicals along the -Z side of the body flap during SSME ignition. Several pieces of the debris were seen to contact the Orbiter LH2 umbilical well door sill (12:45:44.127, 12:45:44.161 UTC), however no damage was detected. (Cameras OTV109, OTV154, OTV163, E1, E4, E17, E18, E19, E20, E31, E34, E76)

A single piece of white-colored debris (ice) from the LO2 TSM T-0 umbilical disconnect fell aft and contacted the midlevel of the +Y/+Z SSME #3 engine bell rim during SSME ignition (12:45:44.703 UTC). No damage to the SSME #3 engine bell was detected. A small piece of white-colored debris was seen falling from a cooling line nozzle on the rim of SSME #1 during SSME ignition (12:45:43.360 UTC). (Cameras OTV151, E17)

A single, small, dark-appearing, piece of debris fell aft from an unidentified area forward of the +Y ET/Orbiter aft attach brace during SSME ignition (12:45:42.66 UTC). (Cameras OTV154)



Figure 2.1 (A) Debris near Base of SSME #3

A single piece of debris (not identified, but possible RCS paper) was seen near the base of SSME #3 and then traveling between SSME #2 and SSME #3 during SSME ignition (12:45:43.837 UTC). See Figure 2.1(A). On camera E18, a small white-colored piece of

## Summary of Significant Events

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debris (possible ice) was seen falling along the left inboard elevon during SSME ignition (12:45:46.758 UTC). The origin of this debris was not determined. (Camera E5, E18)

Several small pieces of debris (probably SRB throat plug material) were seen near the RSRB exhaust nozzle traveling in a southeast direction during liftoff (12:45:49.850, 12:45:49.950 UTC). At least three light-colored pieces of debris from the SRB exhaust nozzle area traveled upward toward the ET aft dome and past the right inboard elevon during SRB ignition (12:45:47.024 UTC). None of the debris appeared to contact the launch vehicle. (Cameras E1, E5, E18)

The following debris was seen near the launch pad during liftoff: A single dark-colored piece of debris was seen on the -Z side of the ET traveling in a northeasterly direction (12:45:48.257 UTC). On camera E5, a single piece of debris (possible RCS paper) was seen on the +Y side of the base of SSME #1 (12:45:49.376 UTC).

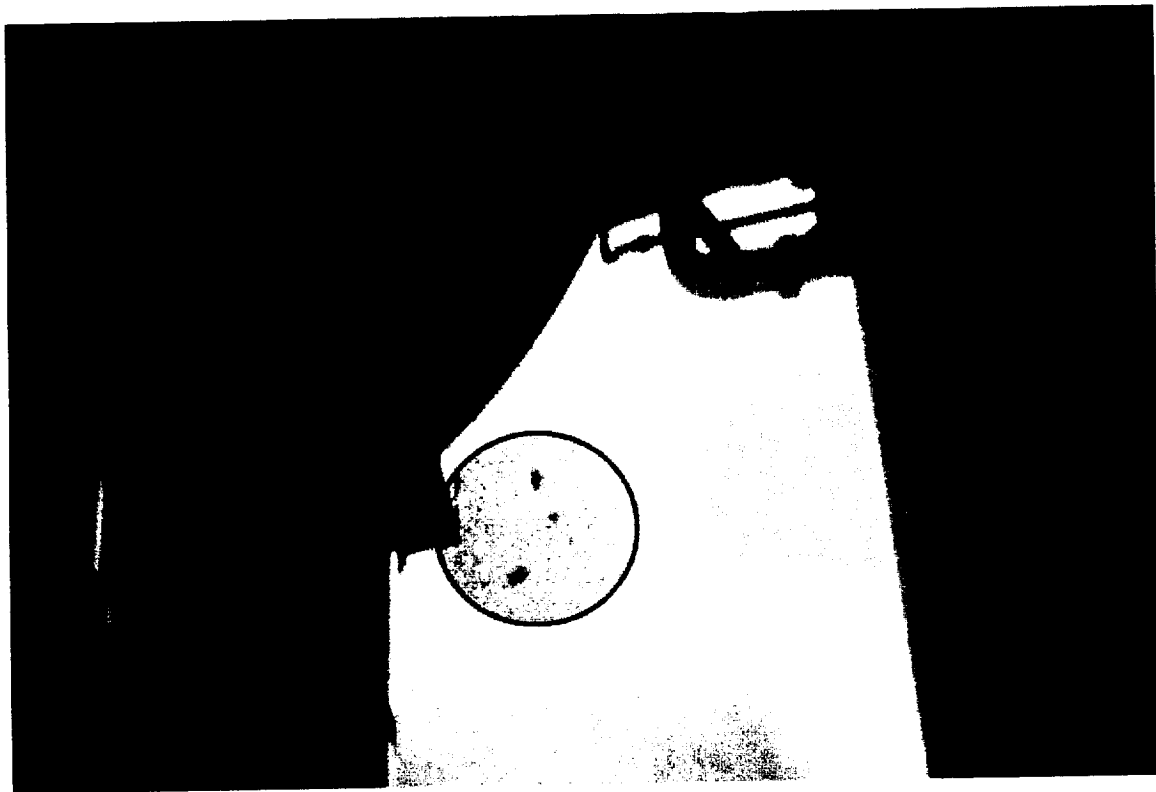


Figure 2.1(B) Debris between LSRB and ET Aft Dome

On camera E31, several small, dark-colored pieces of debris were seen between the LSRB and the ET aft dome (12:45:48.241 UTC). See Figure 2.1(B). On camera E52, a single piece of debris was seen coming from the SRB exhaust nozzle area and moving north away from the vehicle (12:45:49.470 UTC). None of the debris came in contact with the launch vehicle. (Cameras E4, E5, E31, E52)

Several small pieces of debris (possibly ice or frost) were seen falling aft between the ET and the Orbiter forward of the ET/Orbiter umbilicals during liftoff (12:45:50.93 UTC).

## **Summary of Significant Events**

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The debris did not contact the launch vehicle. (Camera OTV161)

### **2.2 DEBRIS DURING ASCENT**

Multiple pieces of debris (mostly umbilical ice, RCS paper debris, and SRB instafoam) were seen falling aft of the launch vehicle during ascent. Examples of debris sightings during ascent are (Cameras E52, E54, E207, E212, E222, E223, E224):

E52 - Debris from an unidentified source was seen in the SSME exhaust plume well aft of the vehicle. (12:45:58.168 UTC)

E52, E54 -Light-colored debris were seen near the RSRB stiffener rings during the roll maneuver. (12:45:58.168, 12:45:49:59.659 UTC)

E222 - A single piece of debris (probably ET/Orbiter umbilical ice) was seen near the right inboard elevon. (12:45:54.200 UTC)

E52, E54 - Multiple pieces of umbilical ice and RCS paper debris were seen throughout the roll maneuver. (12:46:00.9 UTC)

E52 - A single piece of light-colored debris (probably RCS paper) was seen coming over the right wing and past the right elevon. (12:46:03.741 UTC)

E52 - Multiple pieces of ET/Orbiter umbilical ice debris were seen between the SRB aft nozzles. (12:46:04.8 UTC)

E222 - A single light-colored piece of debris (probable RCS paper) was seen in the SSME exhaust plume. (12:46:06.171 UTC)

E52 - A single light-colored piece of debris (probably SRB instafoam) was seen exiting the SRB exhaust plume. (12:46:05.212 UTC)

E54 - A single piece of light-colored debris, first seen near the LSRB, fell aft into the SRB exhaust plume. (12:46:08.681 UTC)

E222 - Multiple pieces of debris were seen in the SSME exhaust plume. (12:46:07.600, 12:46:09.500, 12:46:15.00, 12:46:18.00 UTC)

E223 - A single piece of debris that appeared to be a piece of umbilical well purge barrier material was seen at the aft end of the Orbiter. (Frame 3137)

E222 - Several pieces of debris were seen in SSME exhaust plume. (12:46:20.007, 12:46:22.146, 12:46:29.563 UTC)





Figure 2.2 Debris Exiting RSRB Exhaust Plume

Camera E207 – Debris was seen exiting the RSRB exhaust plume approximately 3.5 seconds prior to SRB separation (~12:47:46.0 UTC). See Figure 2.2.

### 2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims (SSME #2, SSME #3) during SSME ignition (12:45:41.59 UTC). On camera E18, the orange vapor appeared near the base of the LH2 TSM T-0 umbilical disconnect. Orange vapor forward of the SSME rims has been seen on previous mission films and videos. The orange vapor seen on STS-106 was not as apparent as on many of the previous missions, probably because the orange vapor is less visible in the bright daylight conditions of the STS-106 launch. (Cameras E2, E5, E17, E18, E19, E20, OTV170)

The SSME ignition appeared normal on the high-speed engineering films and the SSME Mach diamonds appeared to form in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.3 are from camera film E19.

## **Summary of Significant Events**

---

SSME TIME (UTC)	
SSME #3	12:45:43.808 UTC
SSME #2	12:45:44.093 UTC
SSME #1	12:45:44.109 UTC

Table 2.3 SSME Mach Diamond Formation Times

Faint light-colored streaks, typical of previous missions, were seen extending aft from the SSME nozzle rims prior to liftoff. (Cameras E2, E5):

SSME #1 - 12:45:45.275, 12:45:45.713, 12:45:45.985, 12:45:45.998 UTC

SSME #2 - 12:45:45.839 UTC

A small area of possible tile surface coating material erosion was seen on the base heat shield near SSME #3 during liftoff (12:45:48.449 UTC). On camera E18, three small areas of possible tile surface coating material erosion were seen on the base heat shield near the left RCS stinger. Erosion of the tile surface coating material is typically seen on the launch imagery. (Camera E5, E18)

No indication of holddown post (HDP) stud hang-ups were seen and no debris was seen falling from the HDP stud holes.

PIC firing (SRB ignition) was timed at 12:45:47.019 UTC on HDP M-6, camera film E13.

KSC reported that both of the SRB aft skirt GN2 purge lines were found to be broken during the STS-106 post-launch inspection. However, both the right and left SRB GN2 purge lines appeared intact during the time period they were visible on the holddown posts films. The right SRB GN2 purge line was visible until 12:45:48.888 UTC and the left SRB GN2 purge line was visible until 12:45:48.796 UTC before being obscured by exhaust plumes. (Cameras E8, E13)

### **2.4 ASCENT EVENTS**

Two aft RCS paper covers on the left RCS thrusters did not tear away prior to or during early lift off (as is typically seen). KSC reported that this is not an anomalous event. A similar event occurred on STS-101. (Camera E18)



Figure 2.4 Flares in the SSME Exhaust Plume (Camera E222)

## **Summary of Significant Events**

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Small, light-colored flares were seen in the SSME exhaust plumes during ascent on the intermediate and long range tracking camera films and video between 8 and 47 seconds after liftoff. (See Figure 2.4, Camera E222 Views of SSME Flares):

12:45:54.739 UTC - E52  
12:45:56.127 UTC - E52  
12:45:59.231 UTC - KTV21B  
12:46:11.917 UTC - E222  
12:46:18.502 UTC - E222, KTV4B  
12:46:19.877 UTC - E222, KTV4B  
12:46:21.322 UTC - E222  
12:46:34.320 UTC - E222

Flares in the SSME exhaust plumes have been seen on previous missions films and videos. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris appeared to be RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.)

Body flap motion was seen during ascent with the amplitude and frequency of the motion appearing similar to that seen on previous mission imagery. (Camera ET207, E207)

A dark, gray-colored discoloration was seen in the SRB exhaust plume prior to SRB separation. Discolorations in the SRB exhaust plume during the tail-off prior to SRB separation have been seen on previous mission films. (Camera E223)

The OMS assist burn that occurred after SRB separation was not seen on the films and videos received at JSC. However, MSFC photo analysts reported that they saw the OMS assist burn on camera film E204. (The camera E204 film is not received at JSC).

## **2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-102)**

### **2.5.1 Analysis of the Umbilical Well Camera Films**

#### 16mm Umbilical Well Camera Films

The FL102 (10mm wide angle lens) 16mm umbilical film was not received and was reported by KSC to be a no run (On STS-101, the 5mm wide angle lens 16mm umbilical film was a no run). The FL101 (5mm lens) 16mm umbilical well film was received. The FL101 image quality is good on the SRB and ET separation sequences. However, the exposure is slightly dark. Timing data was present on camera film FL101.

The LSRB separation appeared normal on the 16mm umbilical well camera film. Numerous light-colored pieces of debris (insulation), and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. Numerous irregularly shaped pieces of debris

## Summary of Significant Events

(charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. The amount of ablation of the TPS on the aft dome was typical of previous flights. The SRB nose caps were visible during SRB separation.



Figure 2.5.1(A) Aft ET – LH2 Umbilical

The ET separation from the Orbiter appeared normal. Typical vapor and multiple light-colored pieces of debris (frozen hydrogen) were seen almost continuously before, during, and after the umbilical separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect and between the 1 o'clock position of the LH2 umbilical and the -Y end of the ET cross beam (Figure 2.5.1(A), annotation 1). The red-colored purge seal on the EO-2 ball joint fitting appeared to be in place. (Figure 2.5.1(A), annotation 2).

## Summary of Significant Events

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annotation 1). The red-colored purge seal on the EO-2 ball joint fitting appeared to be in place. (Figure 2.5.1(A), annotation 2).

The extended EO-3 bolt was seen on the 16mm umbilical camera film (Figure 2.5.1(A), annotation 3). (However the extended bolt is imaged at higher resolution on the 35mm umbilical well camera film). See Figure 2.5.1 (C), annotation 6. The detached red-colored purge seal from the EO-3 ball joint fitting clearly imaged on the 35mm umbilical well camera film was also imaged on the 16mm umbilical well film (Figure 2.5.1 (A), annotation 4).

A white-colored piece of debris (probably frozen hydrogen) was seen falling aft along the +Z LH2 tank TPS (Figure 2.5.1(A), annotation 5). The same piece of debris became lodged on the +Y end of the ET cross beam near the -Y side of the LO2 feedline. (This is the same debris seen at higher resolution on the 35mm umbilical well TPS camera views.)

Several small, shallow appearing light-colored marks (possible TPS erosion) were detected on the aft +Z LH2 tanks TPS near the ET cross beam. The largest of these marks was visible on the pre-launch closeout photography.

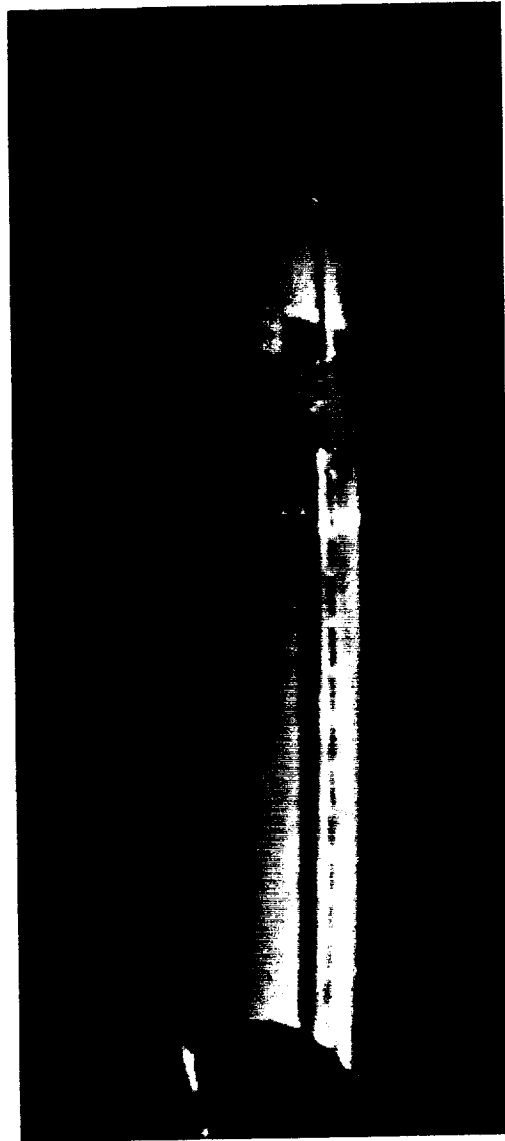


Figure 2.5.1(B) Forward ET with -Y Thrust Panel in Shadow

The -Y thrust panel was in shadow and too dark for analysis (Figure 2.5.1 (B), annotation 1). However, the portions of the LH2 tank, intertank, and Ojive (including the LO2 feedline, press lines, cable trays, and ramps) that were visible appeared to be in good condition. (The divots clearly seen under the forward bipod on the 35mm umbilical well TPS camera film were barely visible on the 16mm FL101 umbilical well camera film.)

### 35mm Umbilical Well Camera Film

Based on the screening of the close-up 35mm umbilical well TPS camera film (roll 406), the ET appeared to be in good condition after the separation from the Orbiter. Fifty-seven excellent quality frames imaging the ET were acquired. The +X translation maneuver was performed on STS-106 to facilitate the imaging of the ET with the umbilical well cameras.

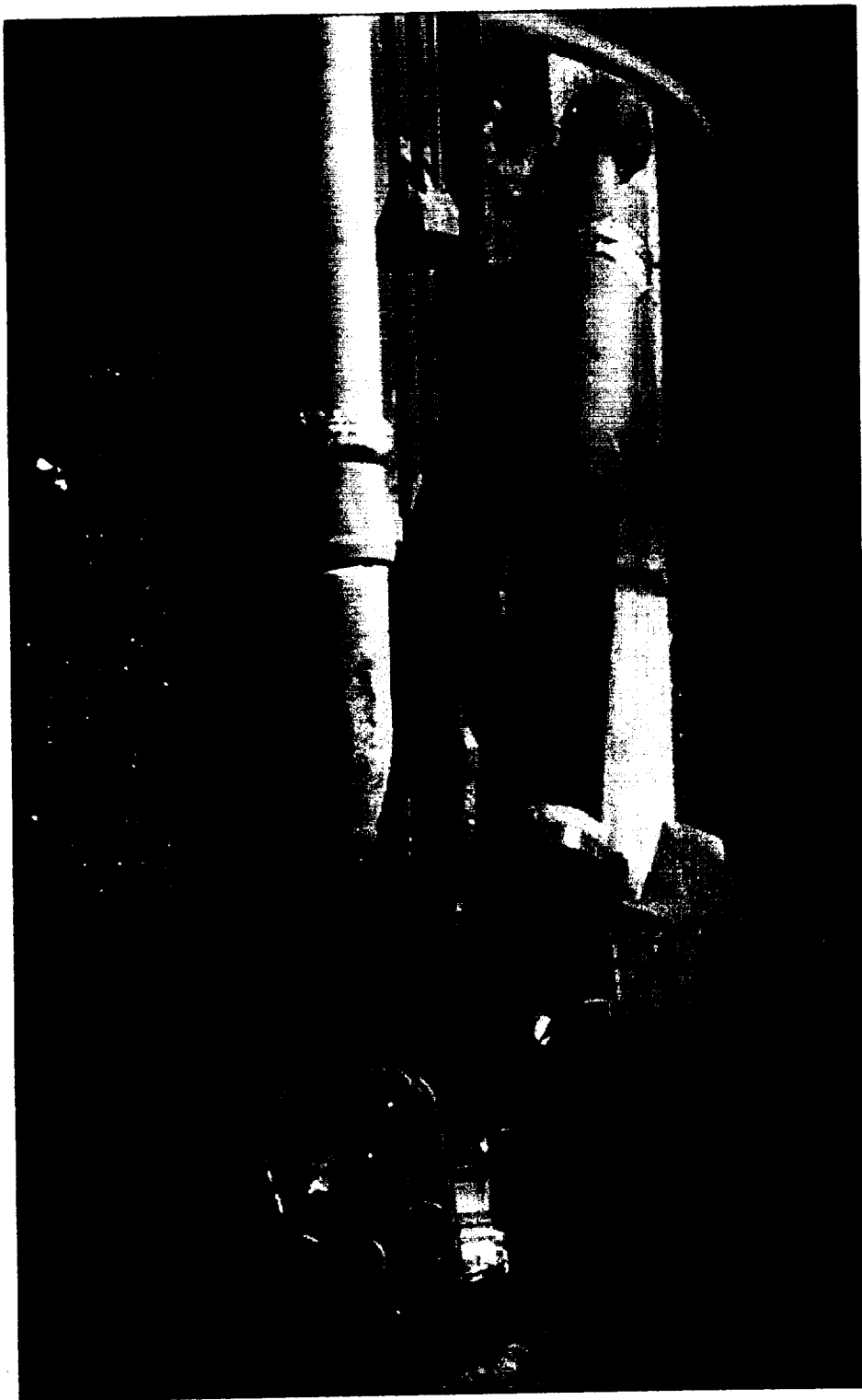


Figure 2.5.1 (C) Aft ET View showing LO2 Umbilical

Minor TPS chipping and very small divots (typical of previous missions) were seen on the aft LO2 feedline flange (Figure 2.5.1 (C), annotation 1) and on the aft bracket over the press lines. Small, shallow areas of TPS erosion and divoting were visible on the +Y



## Summary of Significant Events

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ET/Orbiter thrust strut flange (Figure 2.5.1 (C), annotation 2). Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical were detected (Figure 2.5.1 (C), annotation 3). Small “popcorn” divots, typical of previous mission views, were seen on the ET aft dome (Figure 2.5.1 (C), annotation 4).

What appeared to be a possible up lifting or twisting of a small piece of metallic appearing material was noted on the face of the LO2 17 inch valve at approximately the 7 o'clock position. After further review, it was concluded that the light-tone area giving the appearance of lifting was probably due to the direction of the Sunlight on the face of the LO2 umbilical (Figure 2.5.1 (C), annotation 5). Otherwise, the face of the LO2 umbilical carrier plate appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected).

KSC noted that the EO-3 separation bolt protruded from the fitting and cast a shadow on the face of the LO2 umbilical (Figure 2.5.1 (C), annotation 6). This separation bolt is normally flush or below the surface of the fitting. Imagery analysis support was provided to the Shuttle Program on the ET separation bolt protrusion. See section 2.6.

The red-colored purge seal on the EO-3 ball joint fitting was detached but still in the field-of-view (Figure 2.5.1(C), annotation 7).

A small light-colored, irregular-shaped piece of debris was visible falling aft on frames 13 through 30 (Figure 2.5.1 (C), annotation 8). The debris was last seen near the +Y thrust strut and the aft ET cross beam. The identity of the debris was not confirmed (although the debris appeared to have been a piece of frozen oxygen or hydrogen).

Small “popcorn” divots typical of those seen on previous missions were noted on the aft portion on the LH2 tank TPS just forward of the cross beam (Figure 2.5.1 (C), annotation 9). The +Z/+Y LH2 tank TPS appeared to be in excellent condition.

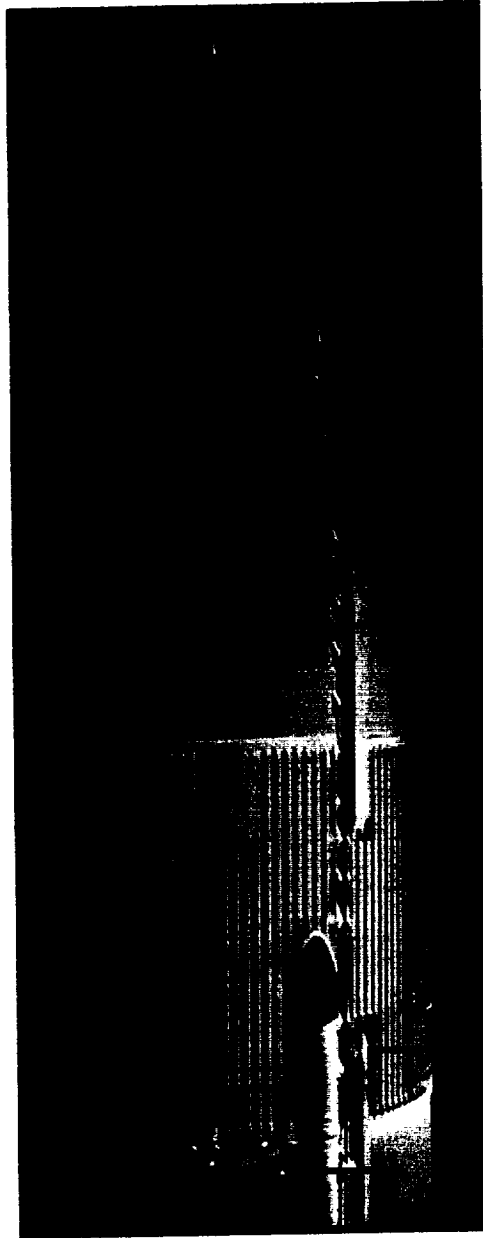


Figure 2.5.1(D) Forward ET

Three divots approximately four inches in size were seen on the LH2 tank-to-intertank flange closeout between the legs of the forward ET/Orbiter attach bipod (Figure 2.5.1(D), annotation 1). A single divot was seen on an intertank rib head just forward of the bipod that was approximately three inches at the maximum diameter and approximately eight inches in length (Figure 2.5.1(D), annotation 2). A single small divot was noted on the LH2 tank TPS just aft of the +Y leg of the bipod (Figure 2.5.1(D), annotation 3). Two small divots were visible in the LH2 tank TPS slightly aft of the -Y leg of the bipod (Figure 2.5.1(D), annotation 4). Both bipod jack pad standoff closeouts appeared to be in good condition.

## **Summary of Significant Events**

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Three divots approximately six inches in size were seen on the LH2 tank-to-intertank close-out flange in the +Y direction from the LO2 feedline (Figure 2.5.1 (D), annotation 5). The forward edge of two of the divots have a dark area that appears to be shadow and / or possibly substrate material.

Overall, the visible portion of the +Z/+Y ET Thrust Panel appeared in excellent condition. However, a cluster of four divots were noted on the rib heads of the +Y ET thrust panel TPS between the +Y forward SRB attach and the LO2 feedline (Figure 2.5.1 (D), annotation 6). The separation burn scar from the RSRB on the +Y ET TPS appeared normal. As expected, the left (-Y) SRB thrust panel was not imaged on this film.

The LO2 tank / Ojive TPS appeared to be in excellent condition. The nose of the ET appeared free of damage and the nose cap appeared in good condition. The aero friction and aero heating marks seen on the TPS just aft of the nose cone appeared similar to the marks seen on STS-90, STS-91, and STS-96 (Figure 2.5.1 (D), annotation 7).

### **2.5.2 ET Handheld Photography**

Thirty-five excellent quality handheld pictures of the External Tank (ET-103) were acquired using the handheld 35mm Nikon F5 camera with a 400mm lens (roll 362). Timing data is present on the film with the first picture being taken at 13:00:41 UTC (14:54 minutes: seconds MET).

The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. (STS-106 was the eleventh flight using the roll-to-heads-up maneuver).

## Summary of Significant Events

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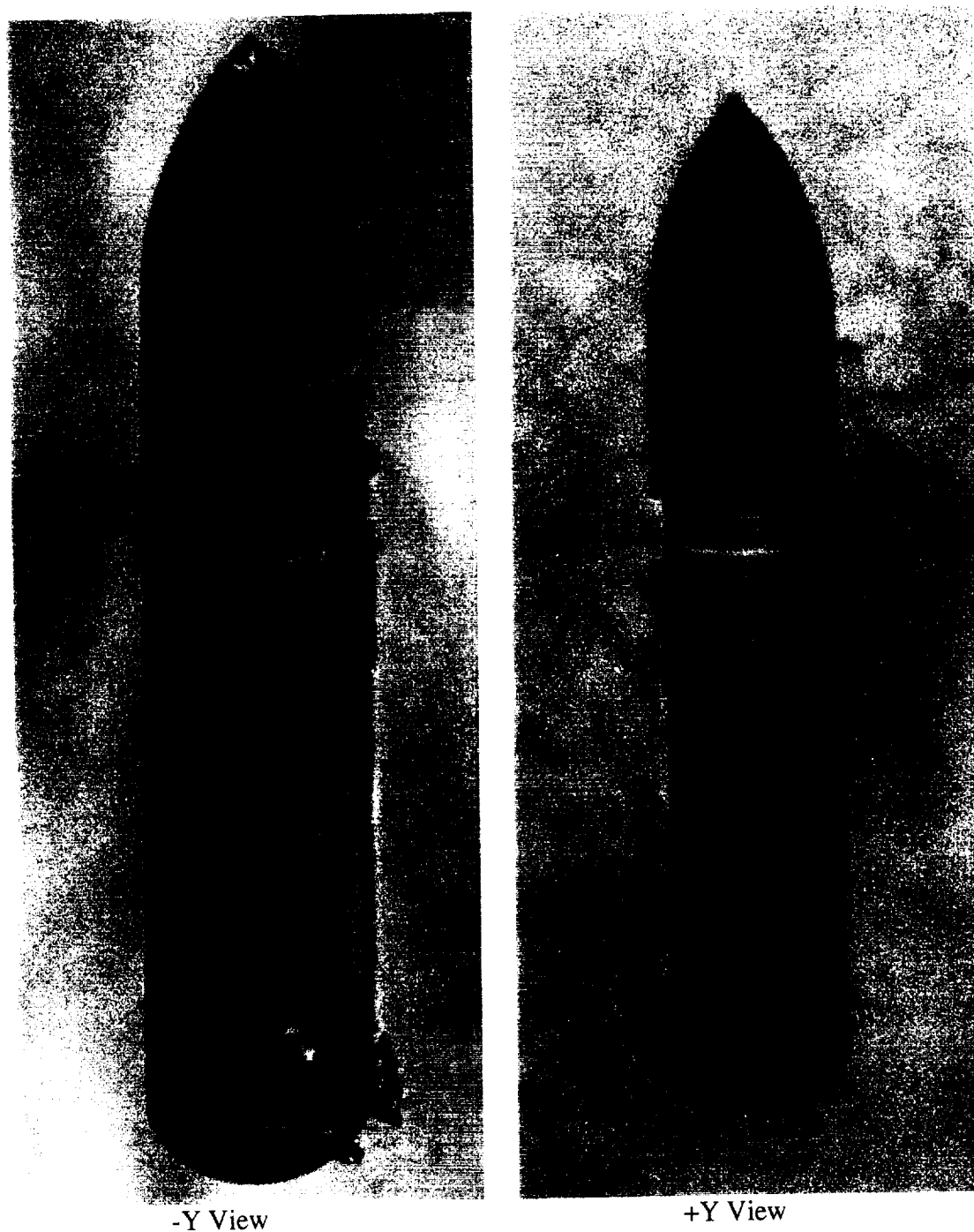


Figure 2.5.2 Handheld ET Views

No anomalous conditions were seen on the handheld imagery of the STS-106 External Tank (ET-103).

Views of the nose, the aft dome, the side of the ET facing the Orbiter (+Z), both limbs (+/- Y sides), and the far side (-Z) of the ET were obtained. The ET was fully illuminated

## Summary of Significant Events

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with very little shadowing. The distance of the ET from the Orbiter was calculated to be approximately 1.6 km on the first photographic frame acquired.

- The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET. The LO2 tank / Ojive TPS appeared to be in good condition.
- A band of eroded TPS (and possible divots) was seen just aft of the ET nose cap.
- A light-colored mark (divot) was visible on the LH2 tank-to-intertank flange closeout between the legs of the forward ET/Orbiter attach bipod. A single divot was seen on an intertank rib head just forward of the bipod. (These divots were seen more clearly on the higher resolution 35 mm umbilical well film.)
- Both of the -Y and +Y ET thrust panels appeared in satisfactory condition (See Figure 2.5.2.) No significant divoting of the TPS on either thrust panel was confirmed from the hand held imagery.
- No divots or unusual marks were seen on the LH2 tank TPS and the ET aft dome.

### 2.5.3 ET Handheld Video

The handheld video was also excellent quality. Approximately five and one half minutes of continuous viewing of the ET was acquired between 12:59:02 and 13:05:12 UTC.

Venting from the ET intertank gaseous hydrogen vent was seen on the crew handheld L2 Camcorder video. The venting was seen to occur in two pulses between 13:01:08 and 13:01:09 UTC. Venting from the ET intertank vent is a normal condition and has been seen on recent previous missions (STS-87, STS-89, STS-90, STS-91, STS-95, STS-99, STS-101).

The tumble rate of the ET was measured to be approximately 5 degrees per second from the video. This rate is similar to the ET tumble rate measured on STS-101. The rate of the ET separation from the Orbiter was estimated to be 8 m/sec which was similar the separation rate measured on STS-101.

## Summary of Significant Events

### 2.6.1 Measurement of the Protruded EO-3 Bolt

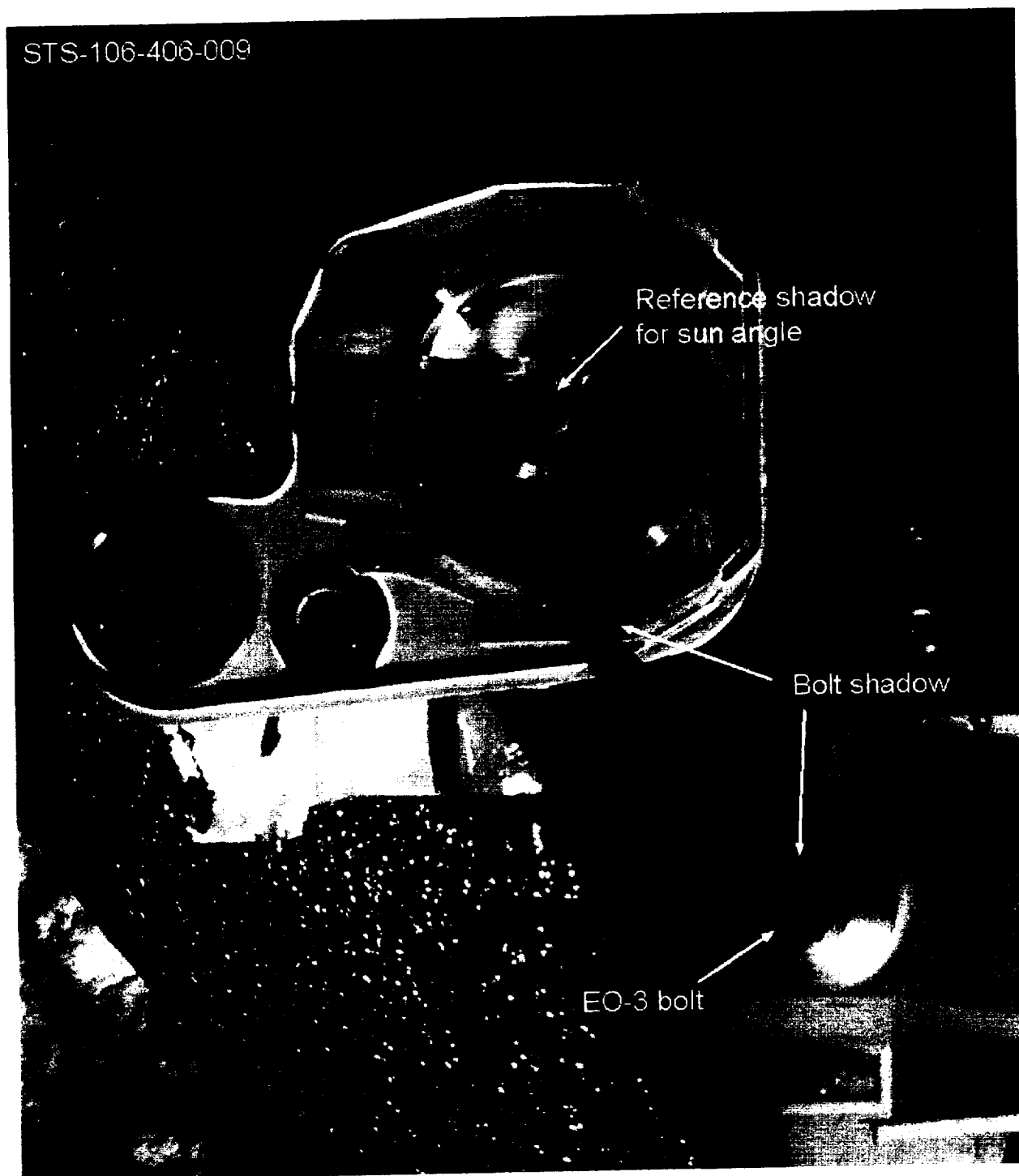


Figure 2.6.1 External Tank EO-3 Protruding Bolt

The unretracted EO-3 bolt seen on the 35mm ET umbilical well film was measured to be protruded 4.0 (+/- 0.25) inches above the plane of the attach fitting. See Figure 2.6.1.

## Summary of Significant Events

The method of measurement was a parallax method using pairs of frames from the film showing the bolt as the ET fell away from the Orbiter.

A second method was used to confirm the earlier result. In this second method, the protrusion of the bolt was determined from the measured length of the bolt shadow using the measured angle of the sun. The angle of the sun was measured to be 24 degrees relative to the ET/Orbiter interface plane using the length of the shadow cast by a 0.55-inch tall circular structure at the center of the 17-inch LO2 feedline. The protrusion of the bolt using the second method was measured to be 3.9 (+/-0.3) inches, which was in agreement with the 4.0 inch measurement using the parallax method.

A multi-frame photogrammetric calculation of the bolt height relative to flush line of the ET EO-3 fitting was also attempted. Due to the combinations of excessively small convergence angle, uncalibrated camera characteristics, and limited 3-D control point data on the ET, the systems of non-linear simultaneous equations failed to converge to a solution. The initial approximations confirmed that the bolt was protruding above the EO-3 surface, but the accuracy of the values was poor.

### 2.6.2 EO Bolt Protrusions seen on Previous Missions Umbilical Films

Previous mission umbilical well camera films were screened for visual evidence of External Tank aft EO attach bolt protrusions, visible bolt heads, and bolt motions by image analysts at KSC, MSFC, and Boeing / Huntington Beach. EO bolts were visible or protruded on the following mission umbilical films:

MISSION	ATTACH FITTING	PROTRUSION/ RECESSED	MOTION
STS-2	EO-2	Protruded	Not Determined
STS-7	EO-2	Protruded	Not Determined
STS-58	EO-2	Protruded	Retracting
STS-58	EO-3	Slight Recess	Lateral Motion
STS-62	EO-3	Recessed	Motion from 12 o'Clock
STS-69	EO-3	Recessed	Up and Down
STS-71	EO-3	Recessed	Up and Down
STS-74	EO-2	Protruded	Up and Down
STS-74	EO-3	Slight Recess	Lateral
STS-75	EO-3	Recessed	Stationary
STS-95	EO-2	Slight Protrusion	Stationary
STS-99	EO-3	Recessed	Receding in Shaft
STS-106	EO-3	Protruding	Stationary

Table 2.6.3 Previous Mission EO Bolt Events

## Summary of Significant Events

### 2.6.3 STS-99 EO-3 Bolt Retraction Rate Calculation

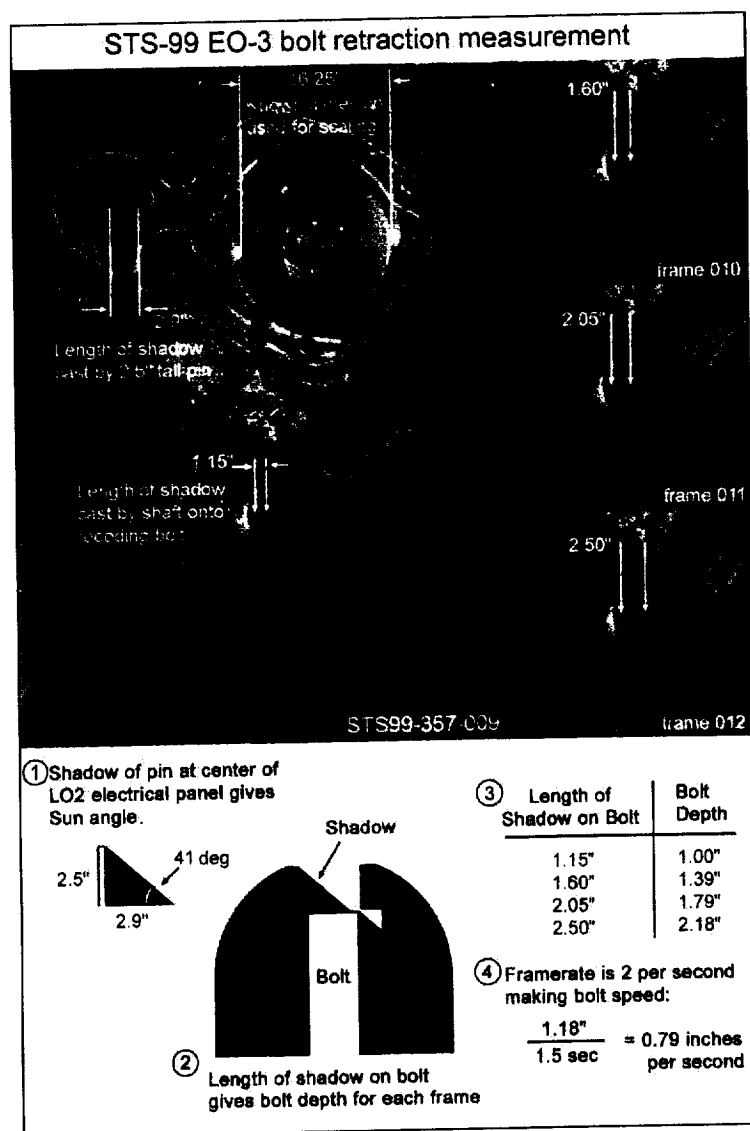


Figure 2.6.3 STS-99 EO-3 Bolt Retraction Analysis

A measurement of the rate of the retraction of the ET EO-3 bolt seen on the STS-99 35 mm umbilical film was requested in support of the investigation into the STS-106 extended bolt. The retraction rate of the STS-99 EO-3 bolt was measured to be 0.8 inches-per-second using four frames from the 35mm film ET umbilical well camera. Just after ET separation from the orbiter, the bolt was seen end-on as it receded into the attach fitting. (see Figure 2.6.3). The velocity of the bolt was measured using the length of the shadow cast by the bolt shaft across the end of the bolt as it retracted inward. Because the shadow cast by the bolt shaft across the end of the bolt was constant at 41 degrees (measured using the relative sun angle for those few frames was constant at 41 degrees (measured using the shadow cast by a 2.5-inch tall pin at the center of the LO2 electrical monoball) the length of the shadow on the bolt provided a measure of the depth of the bolt within the shaft over time. The velocity for the bolt during retraction was calculated using the camera frame rate of 2 frames-per-second.



## **Summary of Significant Events**

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### **2.6.4 STS-74 and STS-58 EO-2 Bolt Retraction Time line**

The External Tank EO-2 bolt was visible in a protruded position on both the STS-74 and STS-58 high speed motion picture umbilical well camera films. Timelines of the bolt retraction were prepared for both of the mission views.

#### **STS-74 EO-2 Timeline**

On STS-74, the EO-2 bolt was extending when first visible on the 16mm umbilical well film (10 mm lens), the bolt hung for approximately one tenth of a second, and then retracted into the fitting. An attempt to measure a "second" rebound was inconclusive because of the poor resolution. The following timeline was constructed using the pre-launch predicted camera frame rate of 240 frames per second:

- 2.14 seconds - Time from first visible ET separation motion until the protruded bolt was visible
- 2.14 to 2.35 seconds - Time from ET separation when the bolt was protruding
- 2.35 to 2.43 seconds - No apparent bolt motion (maximum protrusion before retraction begins)
- 2.43 seconds - Bolt retraction began
- 2.73 seconds - bolt retraction "bottoms out"

#### **STS-58 EO-2 Timeline**

On STS-58, the EO-2 bolt was retracting when first visible on the 16mm umbilical well film (5 mm lens). The following timeline was constructed using the pre-launch predicted camera frame rate of 240 frames per second:

- 2.34 seconds - Time from ET separation (first visible motion) until protruded bolt was visible.
- 2.88 seconds - Bolt retraction from maximum protrusion
- 2.9 seconds - Lateral motion noted
- 3.65 seconds - Bolt flush with fitting
- 4 seconds - Bolt "bottomed out"

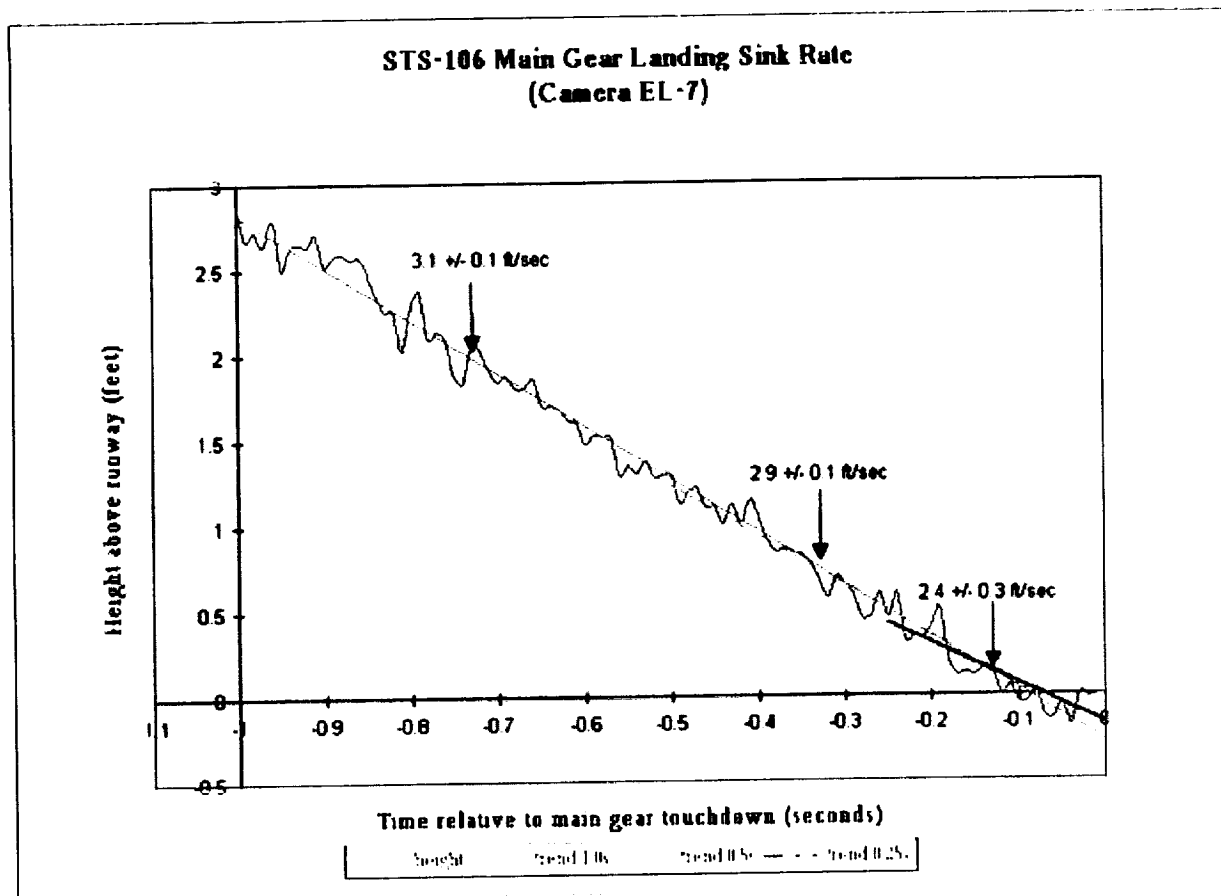


Figure 2.7 Main Gear Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet / second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-106 vehicle was estimated to be 222,800 lbs.

## 2.8 OTHER

### 2.8.1 Normal Events

- elevon motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and / after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff

## **Summary of Significant Events**

---

- debris in the exhaust cloud (including water baffle material) after liftoff
- expansion waves after liftoff
- charring of the ET aft dome
- ET aft dome outgassing
- roll maneuver
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

### **2.8.2 Normal Pad Events**

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical operations
- LH2 and LO2 TSM door closures

## **APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY**



# Space Shuttle Mission STS-106

## Engineering Photographic Analysis Summary Report Marshall Space Flight Center



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## 5. Individual Camera Assessments:

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-106 may be found on the website.

### 5.1 Video Camera Assessments

TV13 - Camera loses track of vehicle in clouds and is unable to acquire vehicle again.  
TV4A - SRB separation time: 252:12:47:49.5 UTC. Several debris induced streaks noted in SSME plumes. Condensation collar observed around vehicle.  
ET204 - SRB separation time: 252:12:47:49.5 UTC. Image quality degraded due to atmospheric haze.  
ET207 - Linear optical distortions and flow recirculation were noted. Cloud cover obscures vehicle at times. Condensation collar observed around vehicle. SRB separation time: 252:12:47:49.5 UTC.  
ET208 - Camera loses track of vehicle in clouds early in ascent.  
ET212 - Clouds obscure vehicle during a majority of ascent.  
ET213 - Camera loses track of vehicle in clouds. Image resolution degraded due to optical reflections and possible water droplets on the lens.  
TV21B - Debris induced streaks noted during roll maneuver.  
OTV109 - Image quality of LH2 umbilical degraded by strong backlight.  
OTV151 - Mach diamond formation in 3-2-1 order.  
OTV163 - Ice noted striking the LH2 Umbilical door sill.

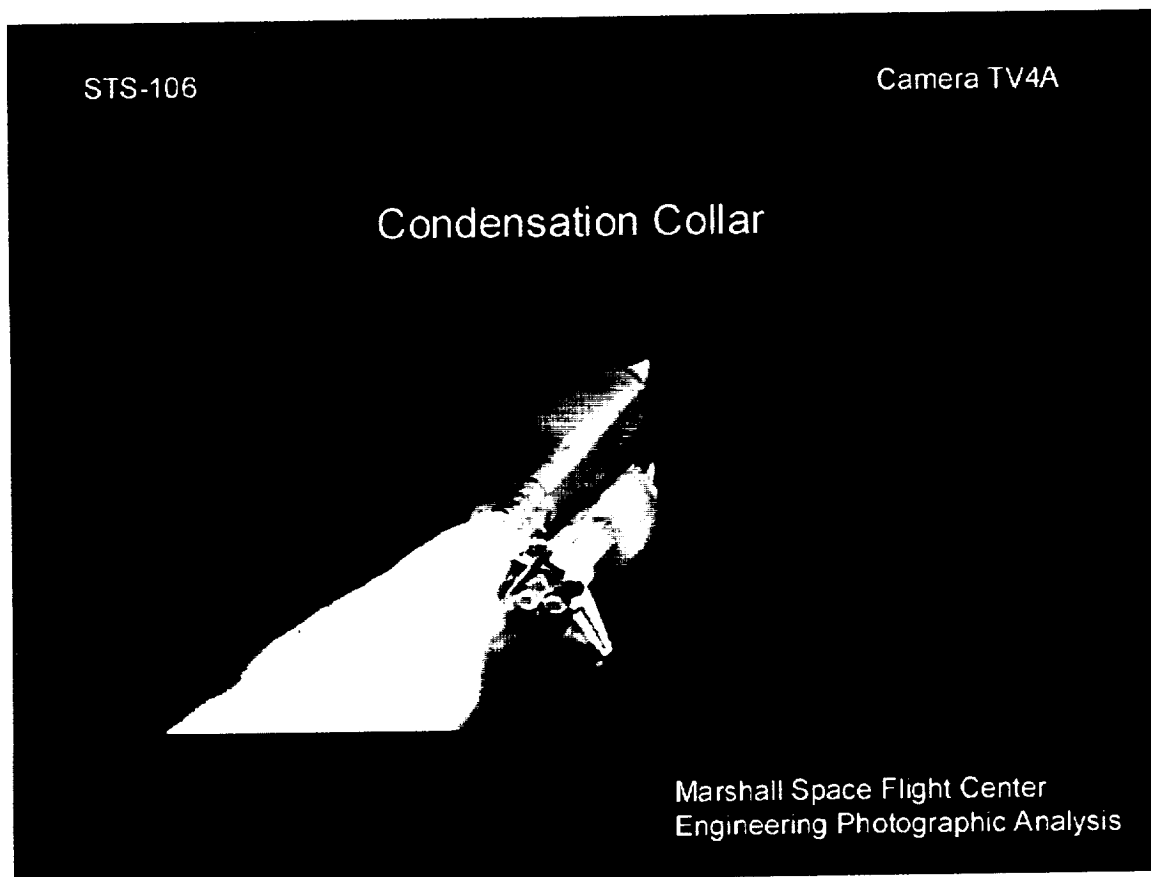
### 5.2 Film Camera Assessments

E19 - Faint engine streaks noted in SSME#1 plume at 252:12:45:45.715 UTC and 252:12:45:45.987 UTC.  
E20 - IRIG time display on film is inaccurate.  
E52 - Debris-induced streak in SSME plume. Engine streaks noted in SSME#1 plume at 252:12:45:45:715 UTC, 252:12:45:56.625 UTC and 252:12:45:56.707 UTC.  
E57 - Camera does not track vehicle.  
E62 - Engine streaks noted prior to liftoff in SSME#1 plume at 252:12:45:45.715 UTC and 252:12:45:45.983 UTC.  
E204 - OMS burn noted after SRB separation. Vehicle obscured by clouds during portions of ascent.  
E207 - Linear optical distortions and flow recirculation were noted. Shock-induced condensation observed. Typical body flap motion was observed. Camera temporarily loses track of vehicle in clouds.  
E208 - Camera loses vehicle in clouds, but reacquires SRB in re-entry.  
E212 - Clouds obscure vehicle during most of ascent.  
E213 - Debris-induced streaks in SSME plume. Camera loses track of vehicle.  
E220 - Image quality reduced due to atmospheric haze.  
E222 - Debris-induced streaks in SSME plume.  
E223 - Linear optical distortions noted. Shock-induced condensation observed. Gray puff in SRB plume, as reported by KSC, was noted prior to separation. Similar plume coloration change events have been noted on previous missions and are not considered anomalous.  
E224 - Debris-induced streaks in SSME plume. Engine streak noted in SSME #1 plume at 252:12:45:56.632 UTC. Two more faint engine streaks were also noted at approximately the same time. Shock-induced condensation observed.  
E2 - Faint engine streaks noted in SSME#1 plume at 252:12:45:45.713 UTC, 252:12:45:45.275 UTC, and 252:12:45:45.998 UTC.  
E3 - Faint engine streaks noted in SSME#1 plume at 252:12:45:45.708 UTC and 252:12:45:45.998 UTC.  
E4 - Typical ice/frost from 17-inch disconnects. Automatic Exposure Control makes image too dark when SRB plumes are present.  
E6 - Ice from LO2 umbilical strikes umbilical well sill. No damage visible.  
E7 - Sound suppression water pipe appears to be leaking from out of field of view of camera.  
E8 - SRB Holddown Post M-2, PIC firing time at 252:12:45:47.018 UTC.  
E9 - SRB Holddown Post M-1, PIC firing time at 252:12:45:47.017 UTC.

## 6. Observations:

### 6.1 Video Camera TV-4A

A "condensation collar" around vehicle was readily visible on this mission. This visible white cloud surrounding portions of the vehicle, the "condensation collar", is due to the change in atmospheric moisture condensing to liquid at the shock boundaries. Condensation collars around the vehicle have been noted on approximately 20 previous Space Shuttle missions.

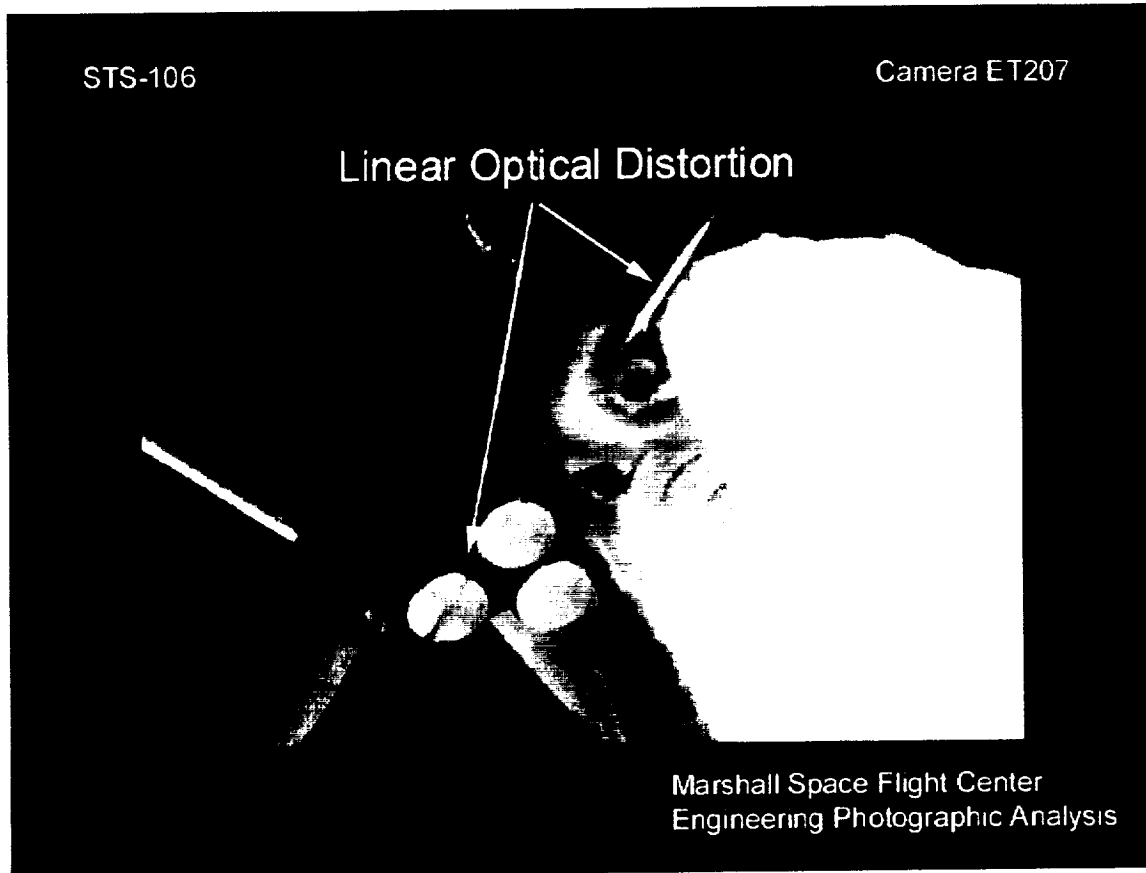


**Figure 1. TV-4A: Shock-induced Condensation Collar**



## 6.2 Video Camera ET-207(A)

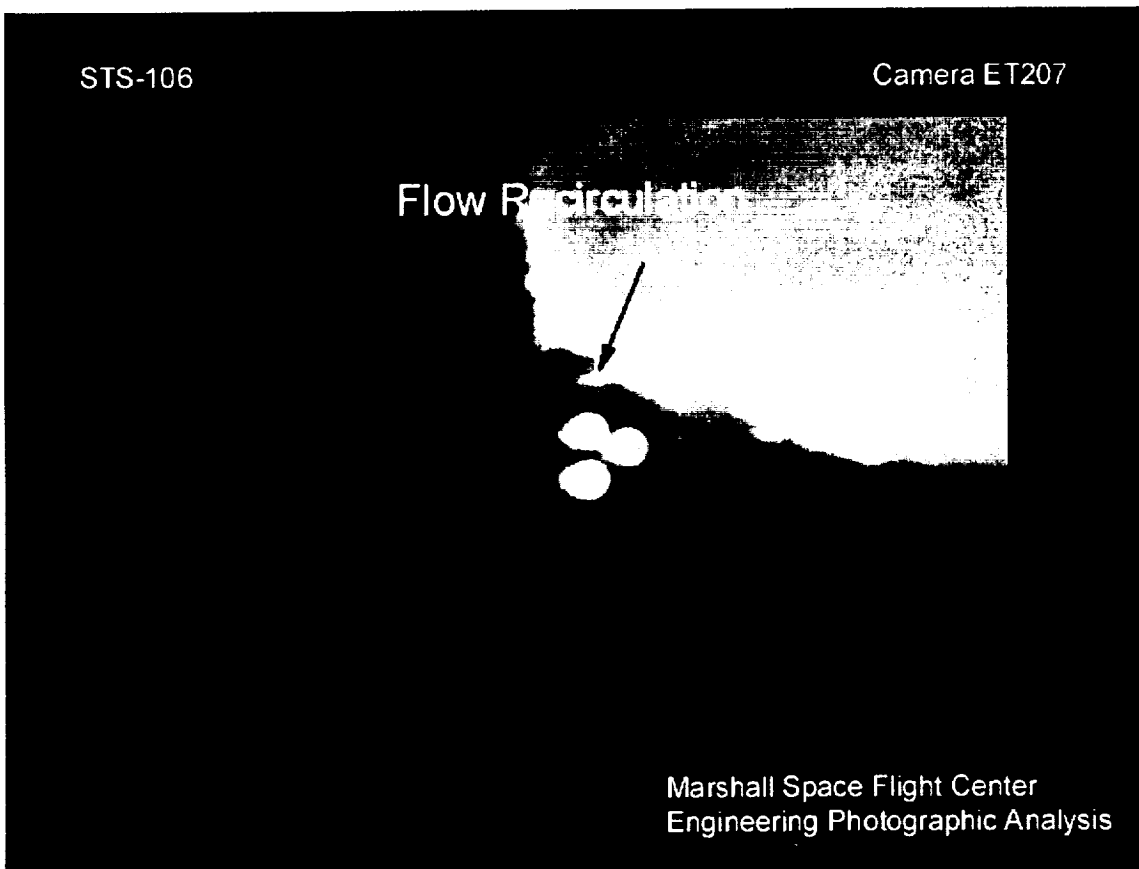
Several linear optical distortions were observed on this mission. These optical distortions are thought to be a result of atmospheric density changes due to shock boundaries. The degree of linearity of the distortion is thought to indicate that the shock wave is distant from the vehicle.



**Figure 2. ET-207: Linear Optical Distortion**

### 6.3 Video Camera ET-207(B)

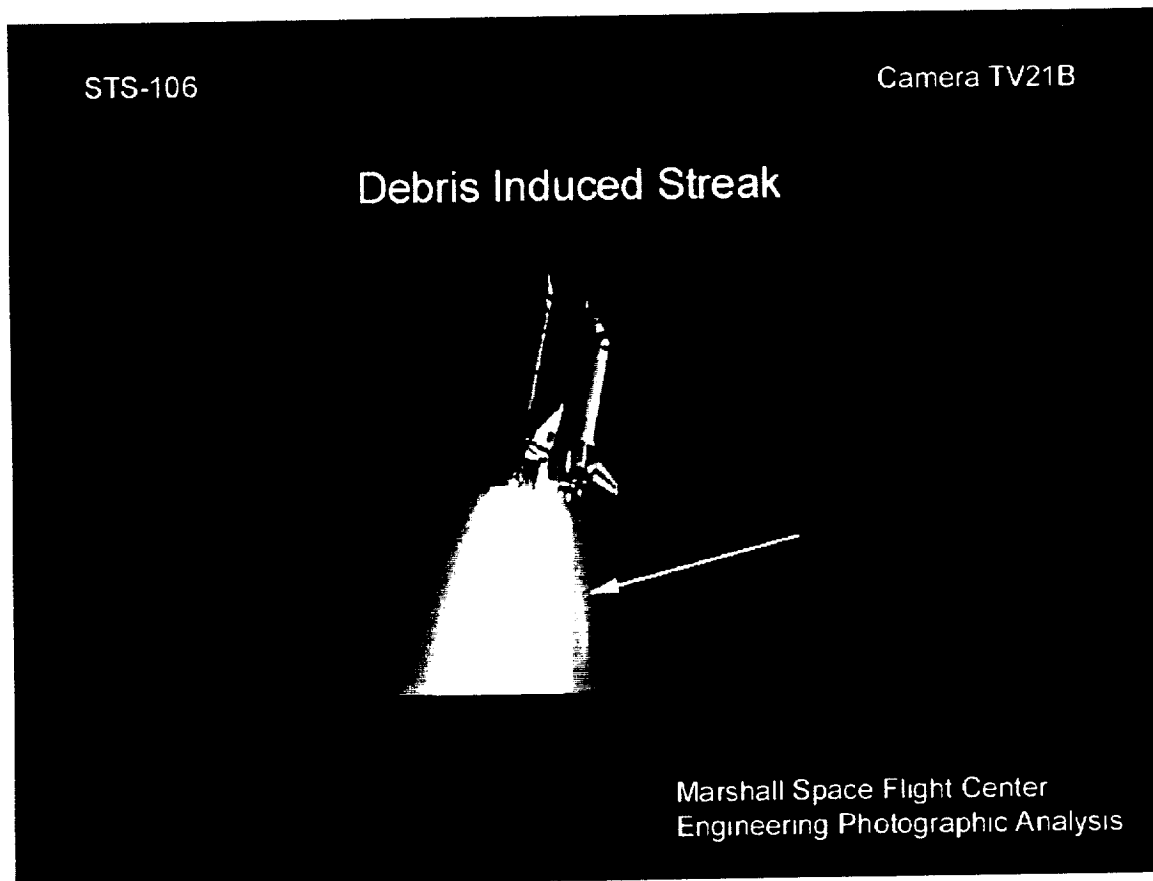
Flow recirculation was evident during this mission. This is a typical event that occurs at approximately 72 seconds into flight. It is due to plume expansion at altitude that restricts the flow of gas from the region near the aft dome of the External Tank.



**Figure 3. ET-207: Flow Recirculation**

#### 6.4 Video Camera TV-21B

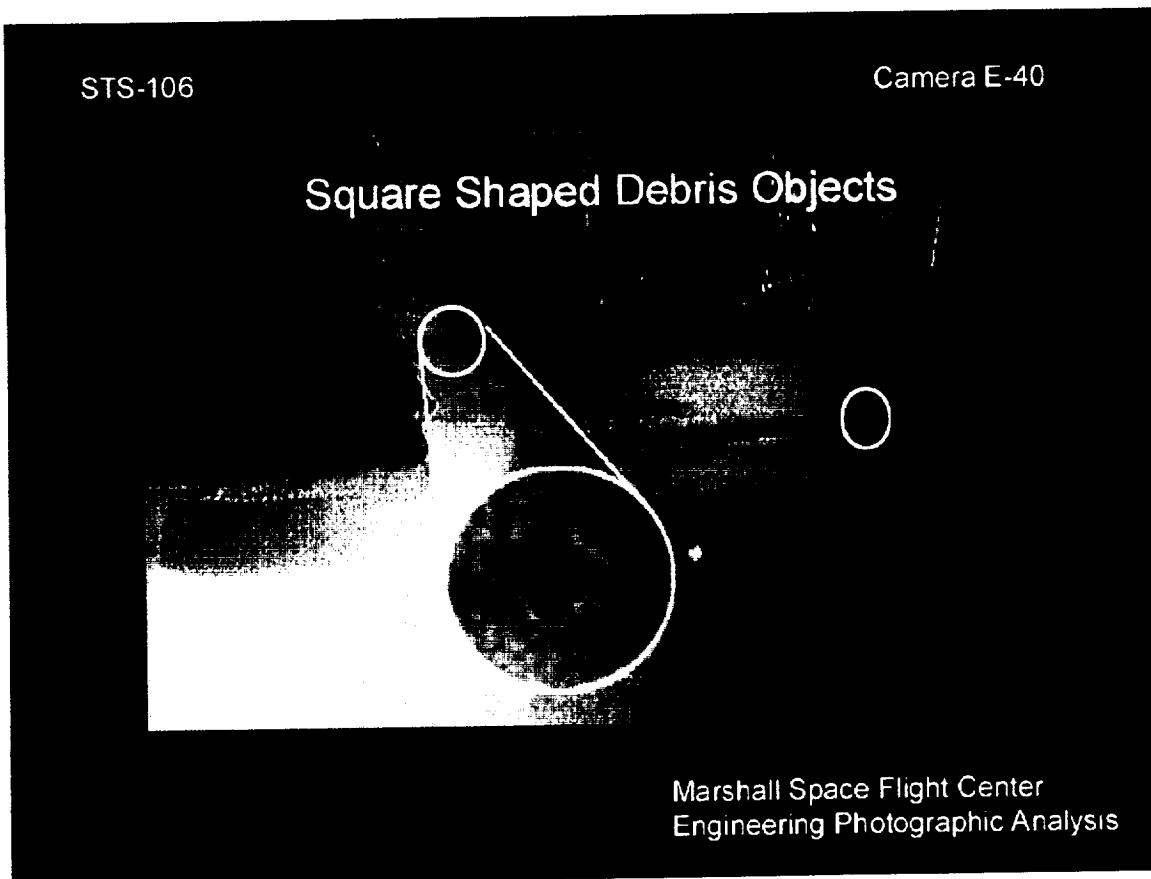
Several debris-induced streaks were observed in the SSME plumes during this mission. The debris-induced streak in Figure 4 occurred just after the roll maneuver during a time in which the RCS nozzle butcher paper covers, hydrogen fire detectors, and purge barrier material, typically detach from the vehicle due to aerodynamic forces. This type of debris is noted on all missions and resulting plume streaks are common.



**Figure 4. TV-21B: Debris-Induced Streak**

### 6.5 *Film Camera E-40*

Two small square flat debris objects were noted falling between the Fixed Service Structure (FSS) and the vehicle. The debris objects were not observed striking the vehicle and appear to be close to the camera. There appears to be notches in two opposing sides of one debris object. The origin of the debris is unknown but is believed to have originated from the FSS.



**Figure 5. E-40: Debris Objects**

## 6.6 Film Camera E-224

Brightening of the SSME #1 plume was observed. The cause of this phenomenon is unknown but is thought to be related to engine streaking.

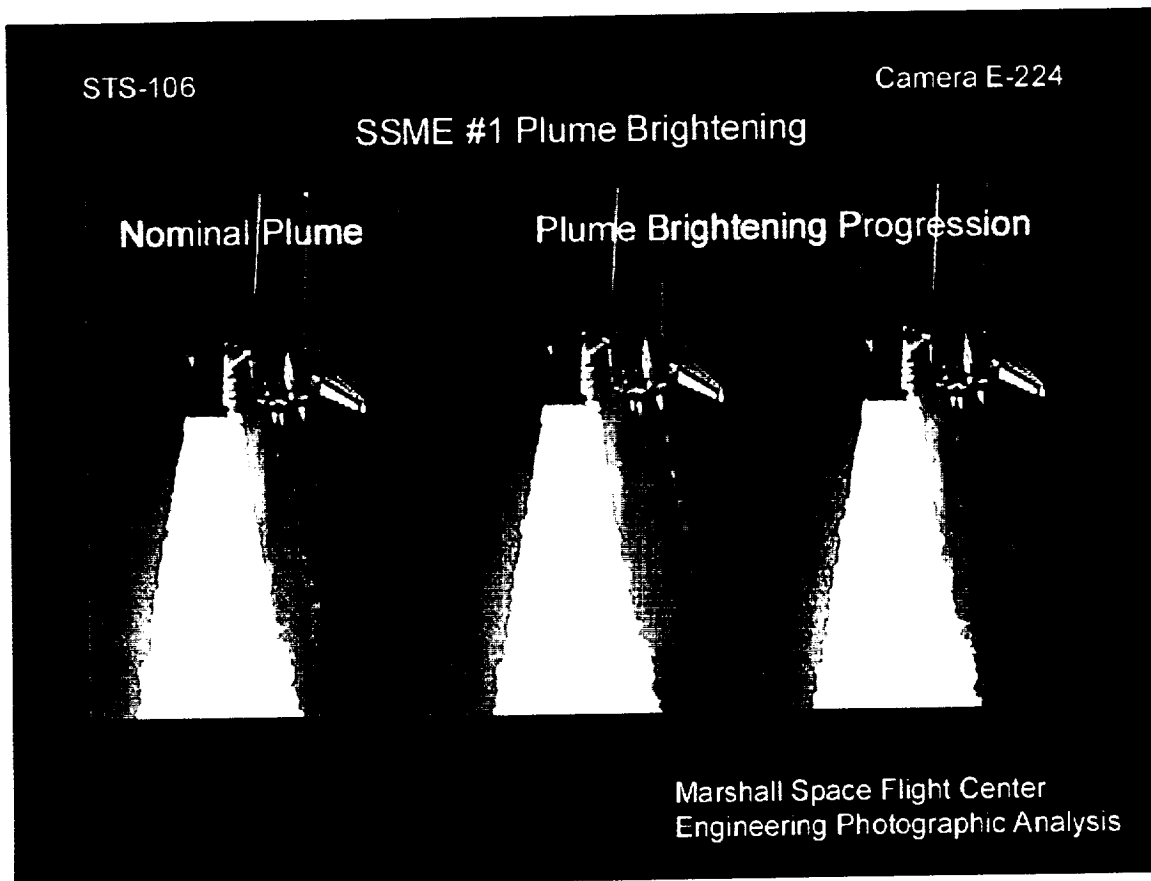


Figure 6. E-224: SSME Plume Brightening

#### 6.7 Umbilical Well 35mm Still Camera (A)

The +Z/+Y areas of the ET appeared to be in good condition. The BSM burn scar on the +Y TPS appeared normal. Normal topcoat charring and TPS erosion on the forward ogive near the nose cone was observed and the phenolic nose cone appeared in good condition. TPS divoting is noted in more detail in following figures.

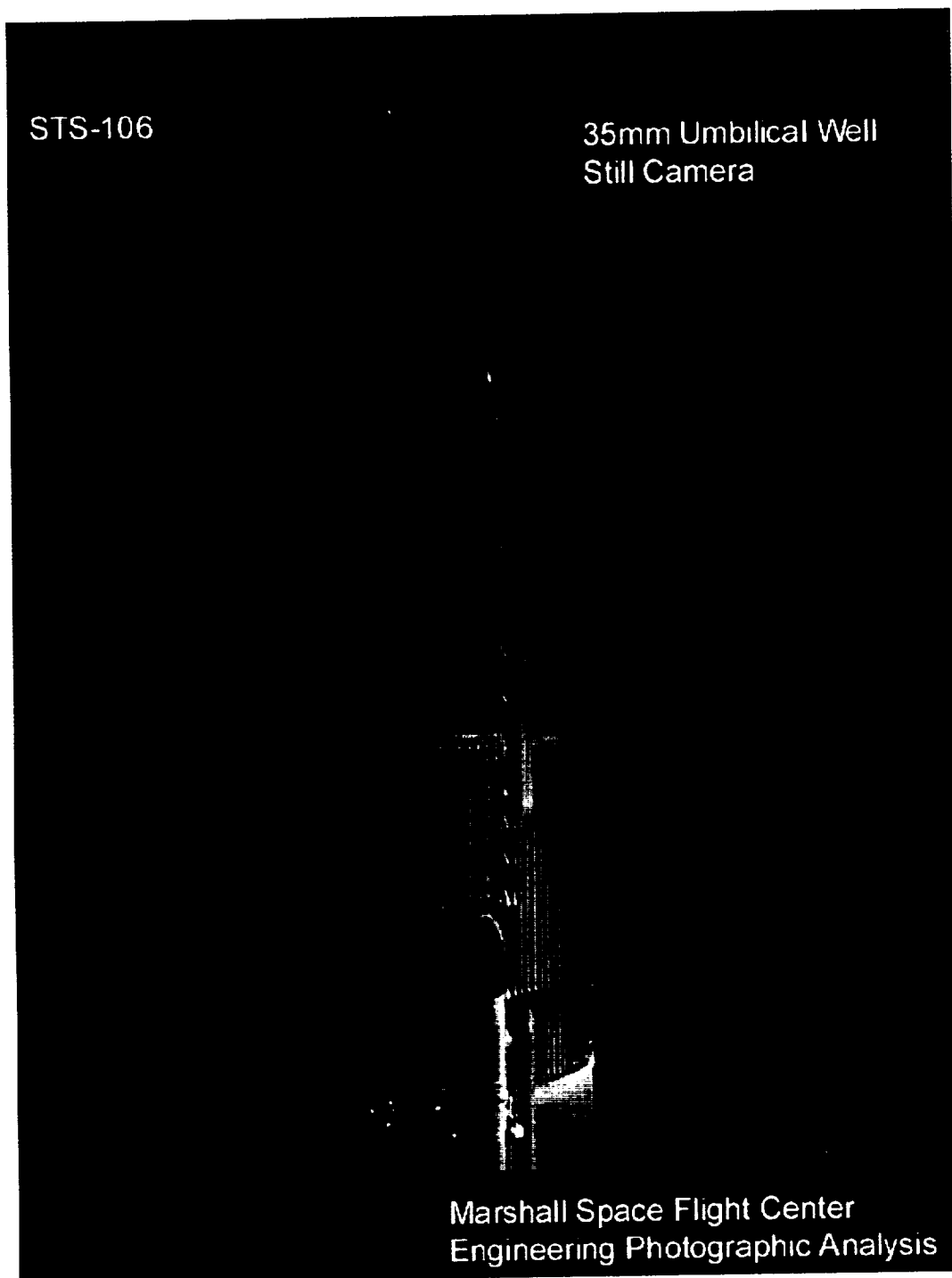


Figure 7. ET Overview

#### 6.8 Umbilical Well 35mm Still Camera (B)

The red-colored purge seal for the EO-3 ball interface fitting is observed tethered to the EO-3 joint. The EO-3 Interface Fitting Separation Bolt protruded from the fitting bore, casting a shadow. Normal 'popcorning' of the aft dome was observed.

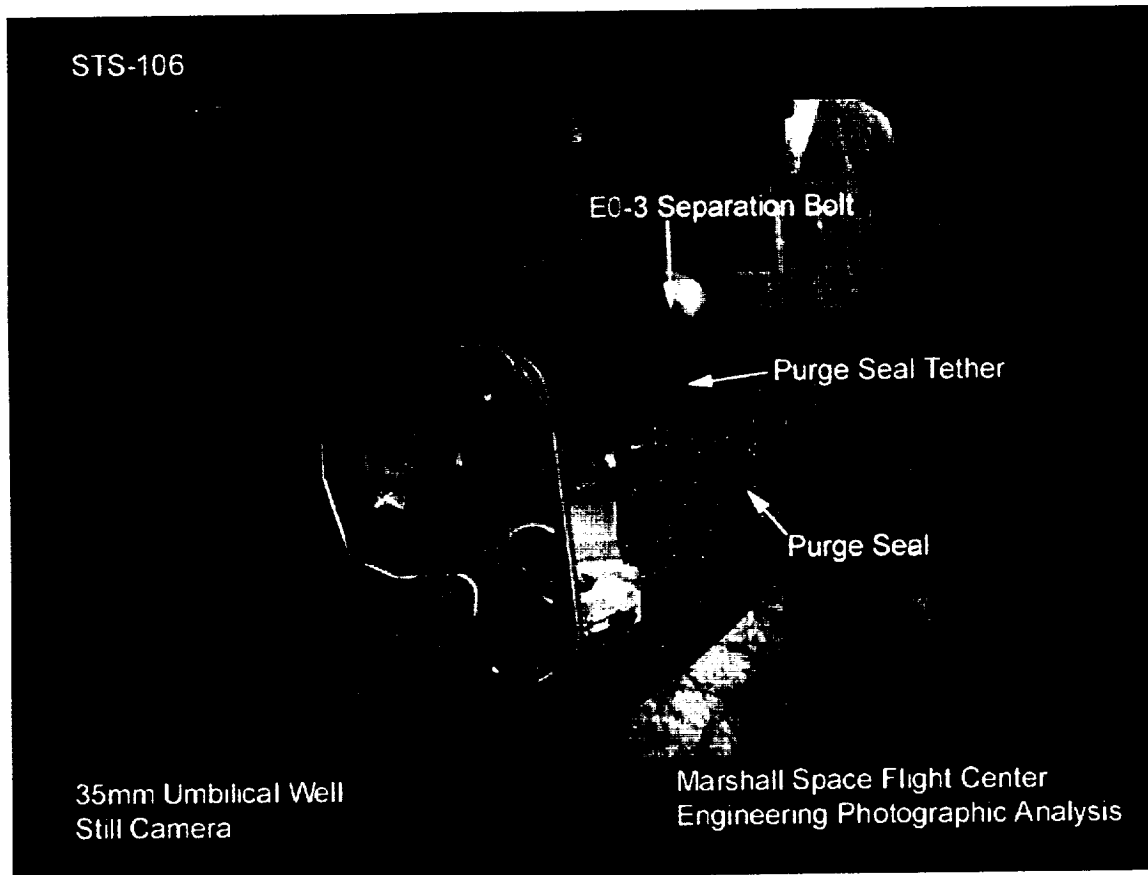


Figure 8. EO-3 Purge Seal

### 6.9 Umbilical Well 35mm Still Camera (C)

The EO-3 purge seal is visible. Normal 'popcorning' of the aft dome and on the LH2 tank acreage is observed. An ice-like debris object was observed near the aft ET Cross Beam. The debris object appeared to impact with the ET Cross Beam.

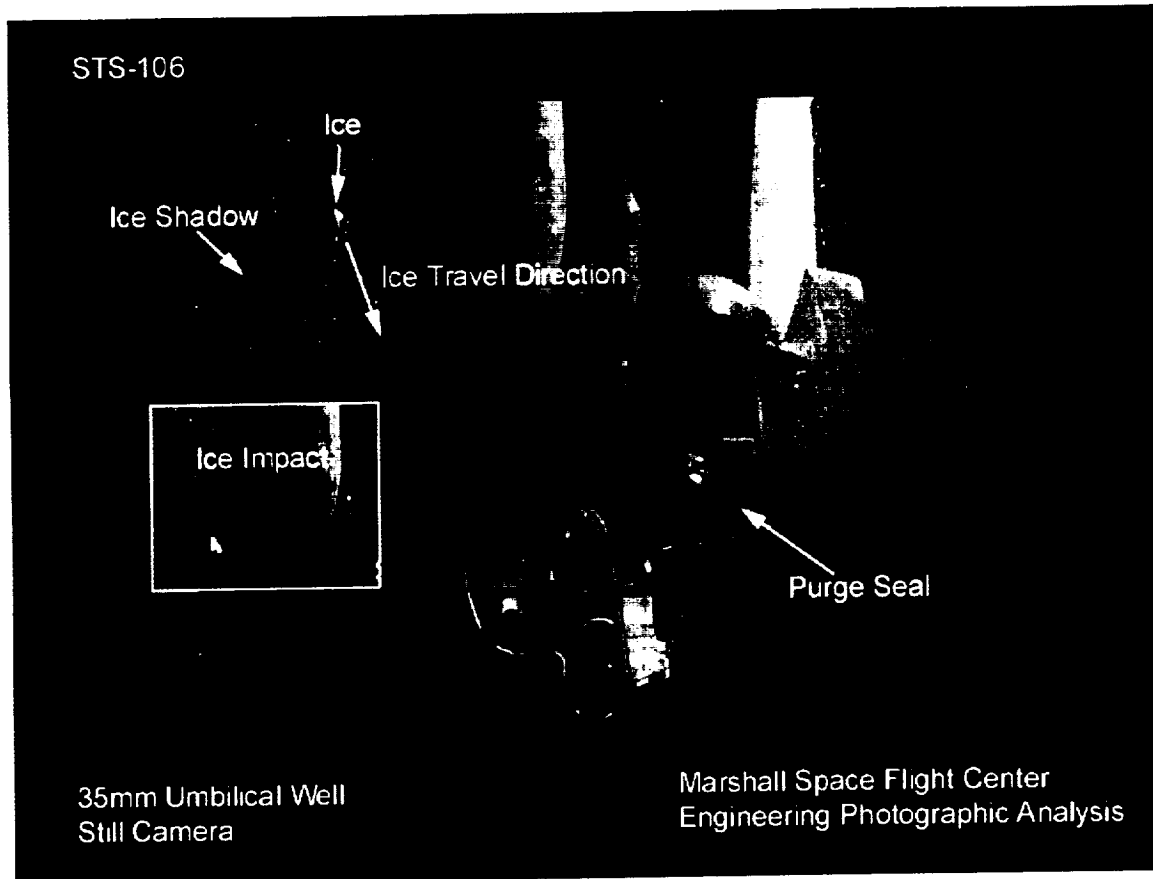


Figure 9. Ice near Aft ET Cross Beam



#### 6.10 Umbilical Well 35mm Still Camera (D)

A number of divots were observed on the Intertank to LH2 Tank Interface and stringer acreage. As noted by arrows in the figure, three divots were observed under the bipod struts, another divot on a stringer near the center of the bipod, and three more divots located between the LO2 feedline and the +Y thrust panel. Smaller divots can be observed on the LH2 Tank acreage near the bipod and on stringer area to the -Y and the +Y side of the bipod.

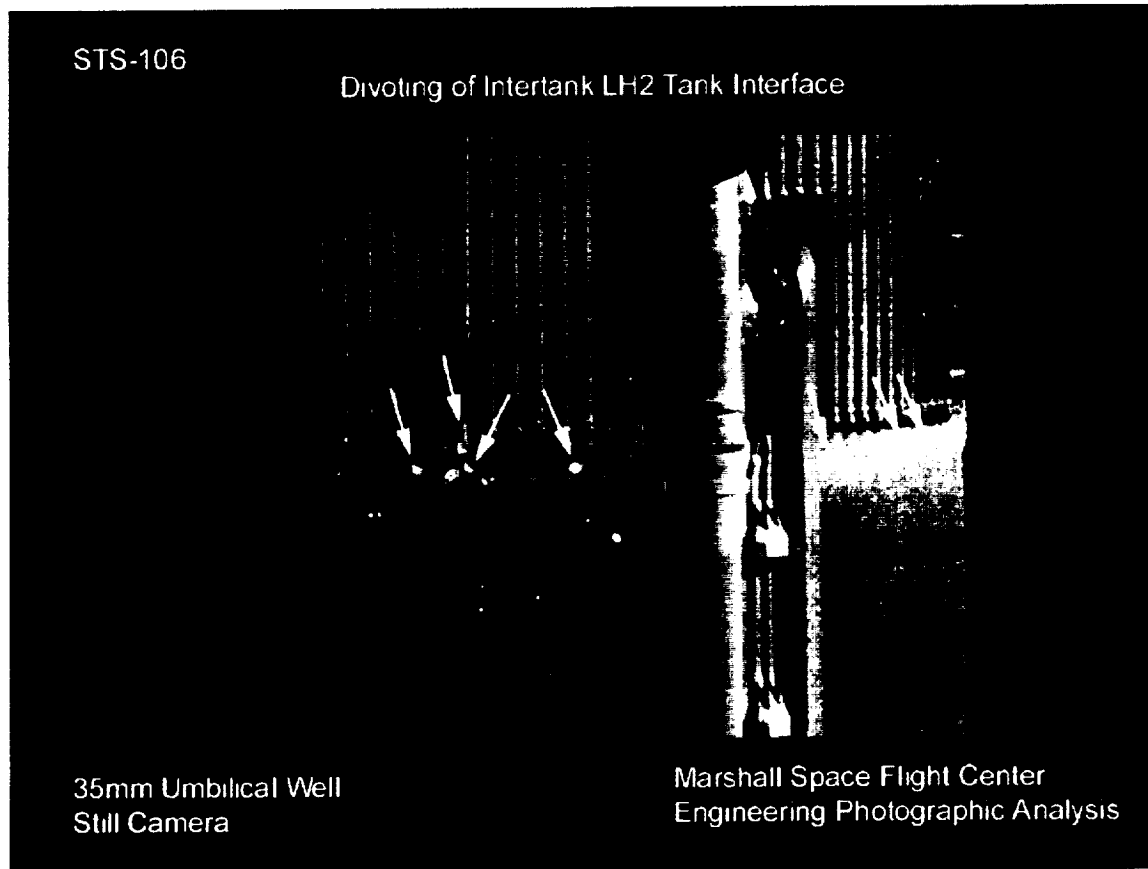


Figure 10. Divoting Observed on LH2 to Intertank Interface

### 6.11 Umbilical Well 35mm Still Camera (E)

Several divots were observed on the tops of stringers between the LO2 Feedline and the +Y Thrust Panel, including a cluster of five divots noted in the figure.

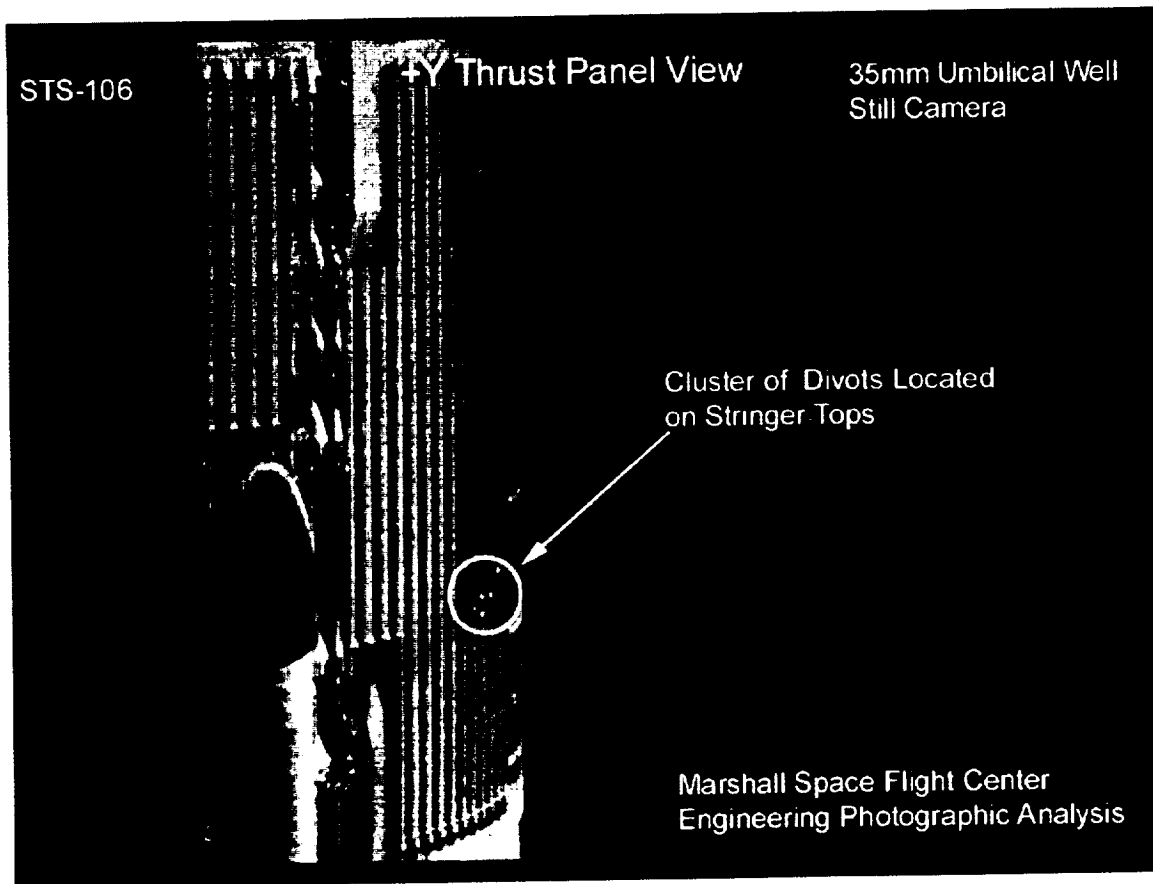
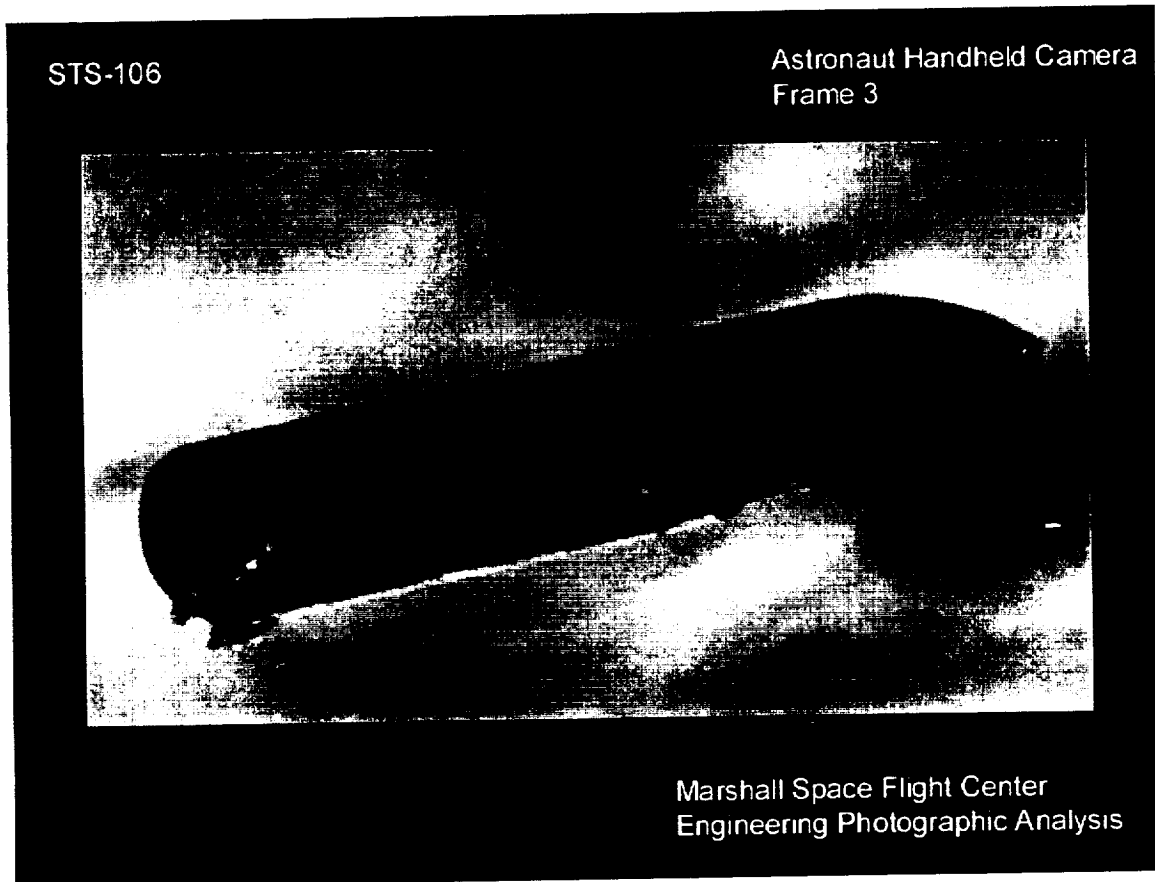


Figure 11. Divoting Observed near +Y Thrust Panel

**6.12 Astronaut Handheld 35mm Still Camera (A)**

Normal SRB separation burn scars on the intertank and aeroheating marks on the nose TPS were noted on the -Y side of the ET. Divoting was hard to discern at the resolution of these pictures, but was visible in the Umbilical Well imagery. Possible divoting of the LH2 to Intertank Interface in the -Y (left) direction from the bipod is indicated.



**Figure 12. Astronaut Handheld Camera View of -Y Side of ET**

### 6.13 Astronaut Handheld 35mm Still Camera (B)

Normal SRB separation burn scars on the intertank and aeroheating marks on the nose TPS were noted on the +Y side of the ET. Divoting was hard to discern at the resolution of these pictures.



**Figure 13. Astronaut Handheld Camera View of +Y Side of ET**

#### 6.14 Astronaut Handheld 35mm Still Camera (C)

Normal charring of the aft dome TPS was noted on the ET. Divoting was hard to discern at the resolution of these pictures. The ET +Z side appears normal.

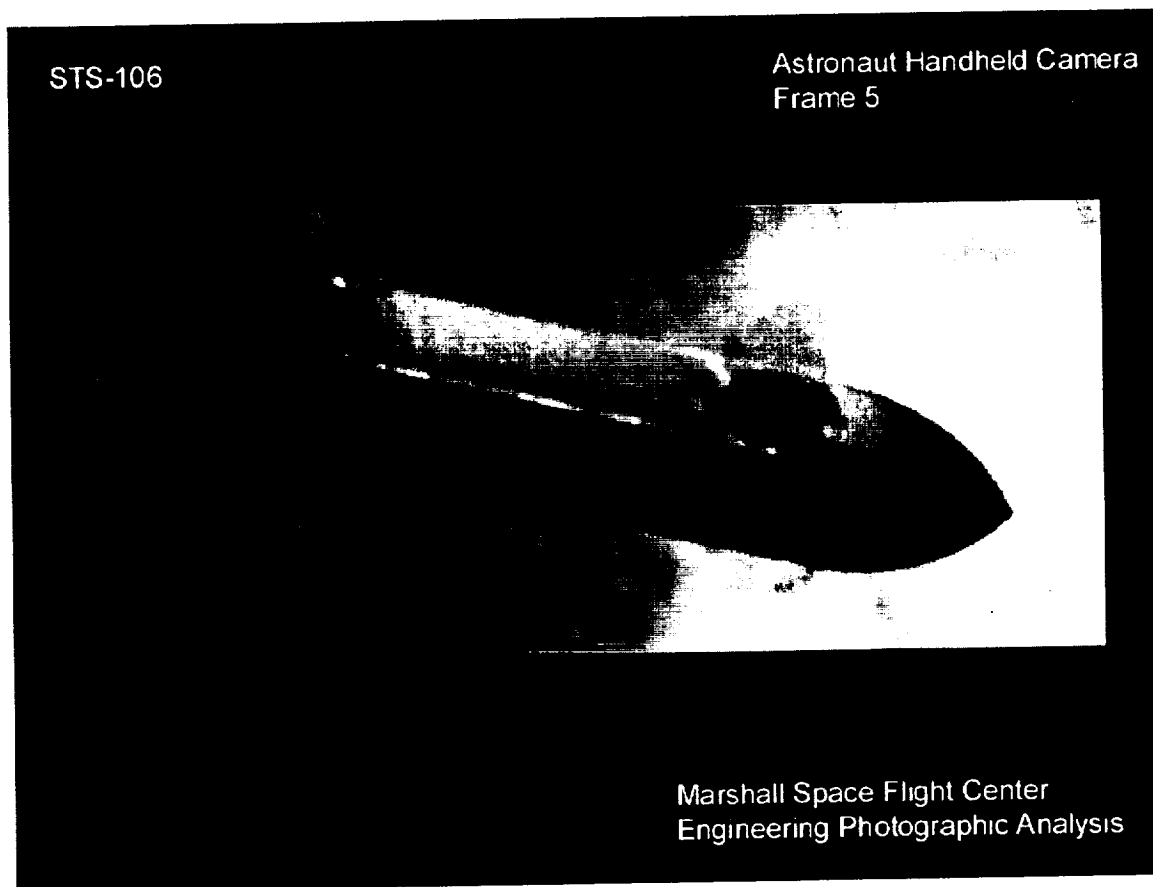
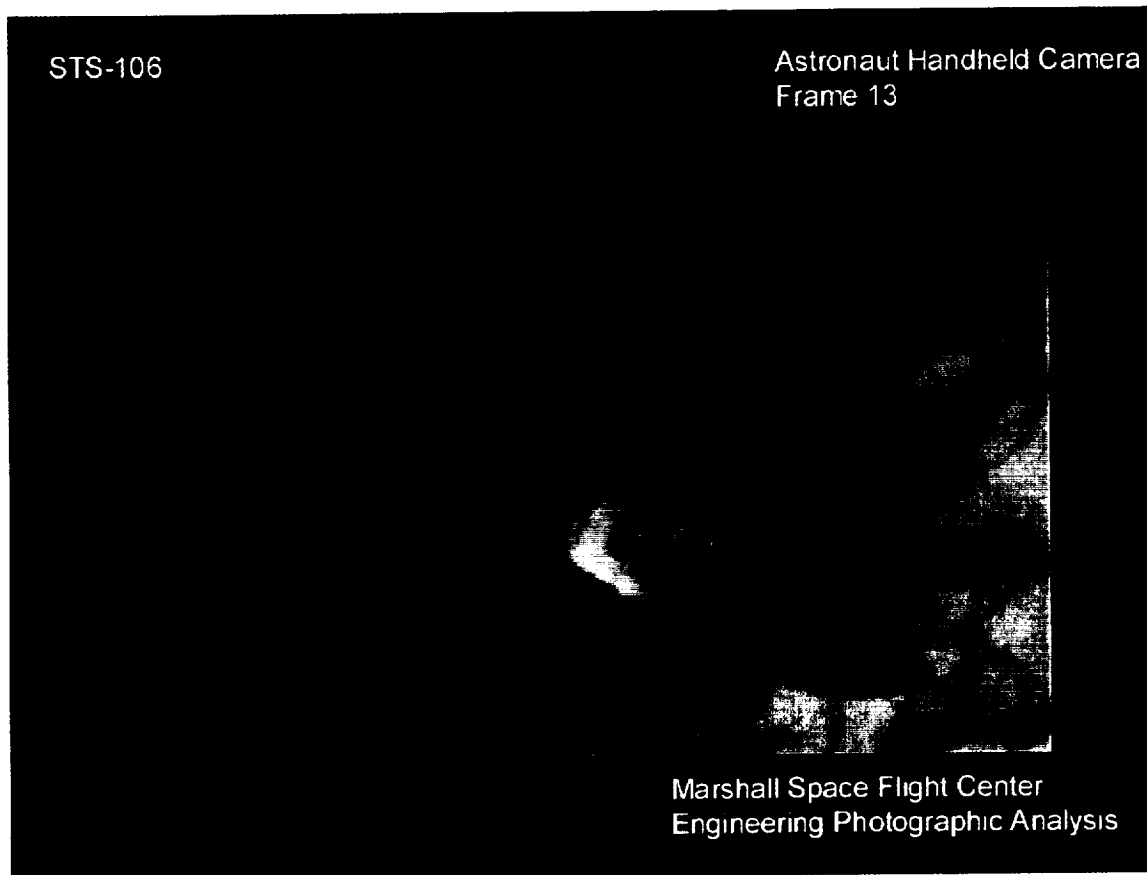


Figure 14. Astronaut Handheld Camera View of Aft and +Z Side of ET

**6.15 Astronaut Handheld 35mm Still Camera (D)**

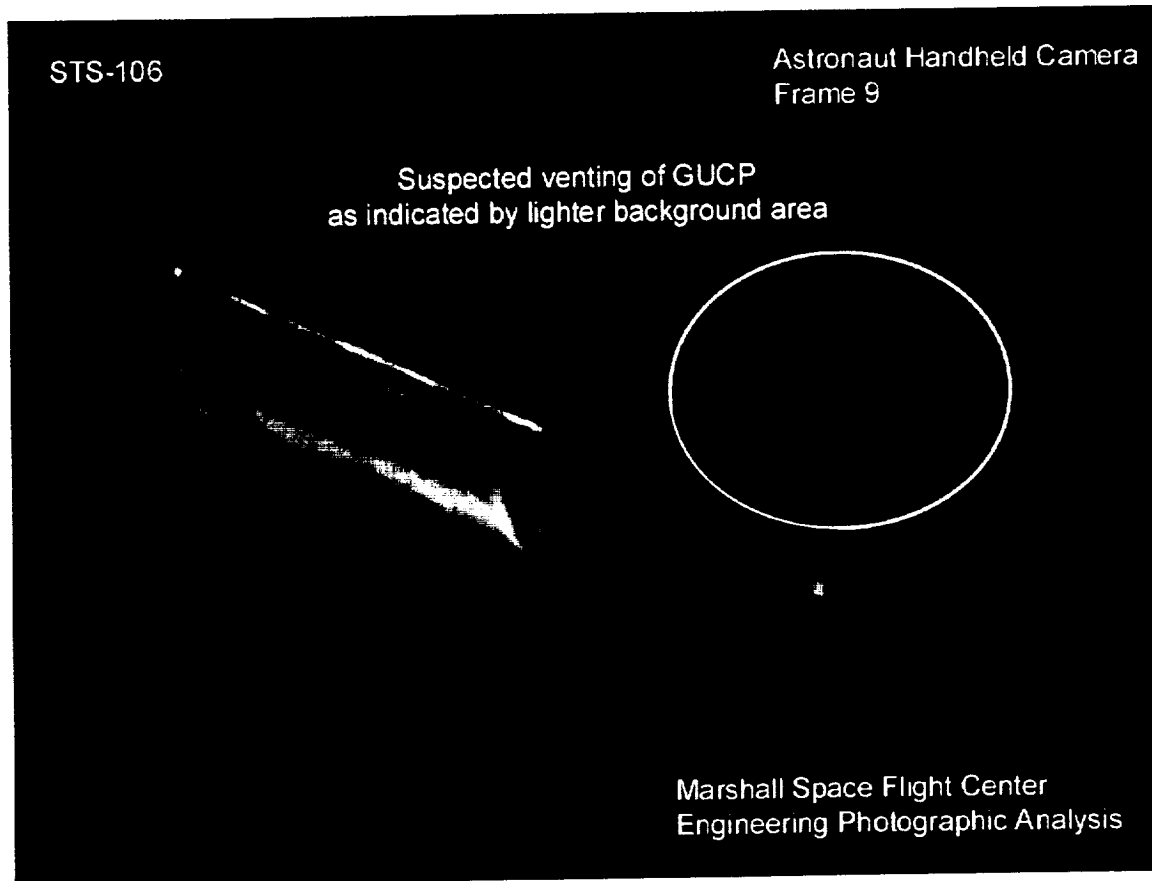
Aeroheating marks on the nose TPS and the -Z side of the ET appear normal. Divoting was hard to discern at the resolution of these pictures.



**Figure 15. Astronaut Handheld Camera View of -Z Side of ET**

**6.16 Astronaut Handheld 35mm Still Camera (E)**

Normal SRB separation burn scar noted on ET +Y acreage observed. Lighter background area, circled in Figure 16, indicates possible venting from GUCP on ET.



**Figure 16. Astronaut Handheld Camera View of Venting from ET**

### 6.17 Astronaut Handheld Video Camera

Venting from GUCP on ET is shown from the astronaut handheld video camera view at two different times.

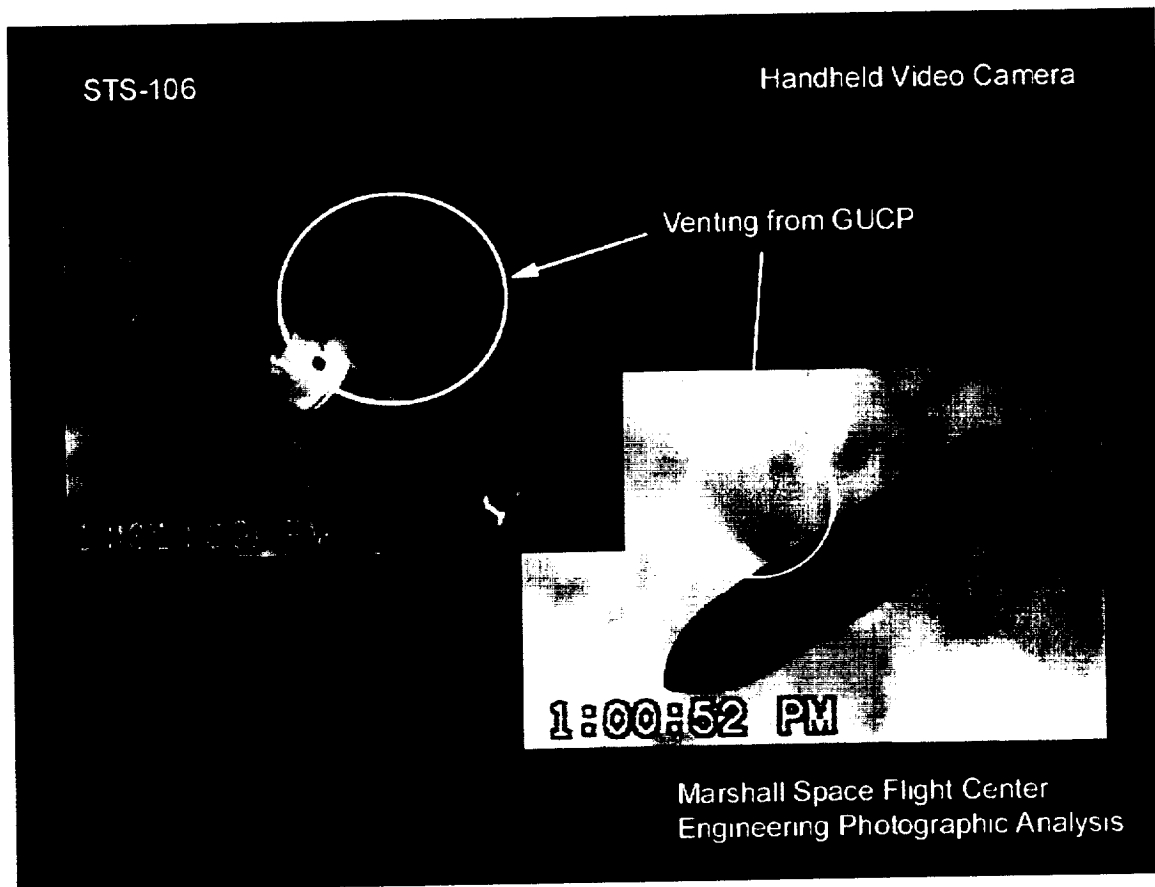


Figure 17. Astronaut Handheld Video Camera View of Venting from ET



## **7. Special Investigations**

### **7.1 *Historical Review of Umbilical Well Cameras Supporting EO-3 Interface Bolt Protrusion Investigation***

The EO-3 interface fitting bolt was observed protruding from the bore of the ball fitting during this mission. This event was determined to be an issue and a NASA-wide team was formed to review past missions for other occurrences of EO-2 or EO-3 interface bolt protrusion. MSFC Engineering Photographic Analysis was tasked to review the last six missions.

Each mission typically has three umbilical well cameras. Two onboard 16mm-motion picture film cameras that primarily view the LH2 Disconnect and EO-2 interface fitting areas. One motion picture camera has a 5mm wide angle lens the other a 10mm lens. The 35mm film still camera primarily views the LO2 Disconnect and EO-3 interface fitting areas and records images at 0.5-second intervals.

The results of the review of these cameras indicated that separation bolts had been visible or protruding nineteen times from Forty-one missions reviewed, as reported to the STS-92 Delta Pre-Launch MMT by John Mulholland. United Space Alliance reports that STS-92 was found acceptable for flight based on identification of bolt rebound as the most likely cause of the bolt protrusion during film review and the bolt ejection timeline showing no potential for the bolt to hang up on the orbiter.

### **7.2 *Study of Separation Bolt Shadows***

It was noted that the shadow from the separation bolt falling on the LO2 Disconnect face plane had changed, Figure 18, the shadow cast on the Disconnect face plane is observed to be longer in Frame 7 than in Frame 19. This led to a conjecture that this shadow change was a result of movement of the bolt.

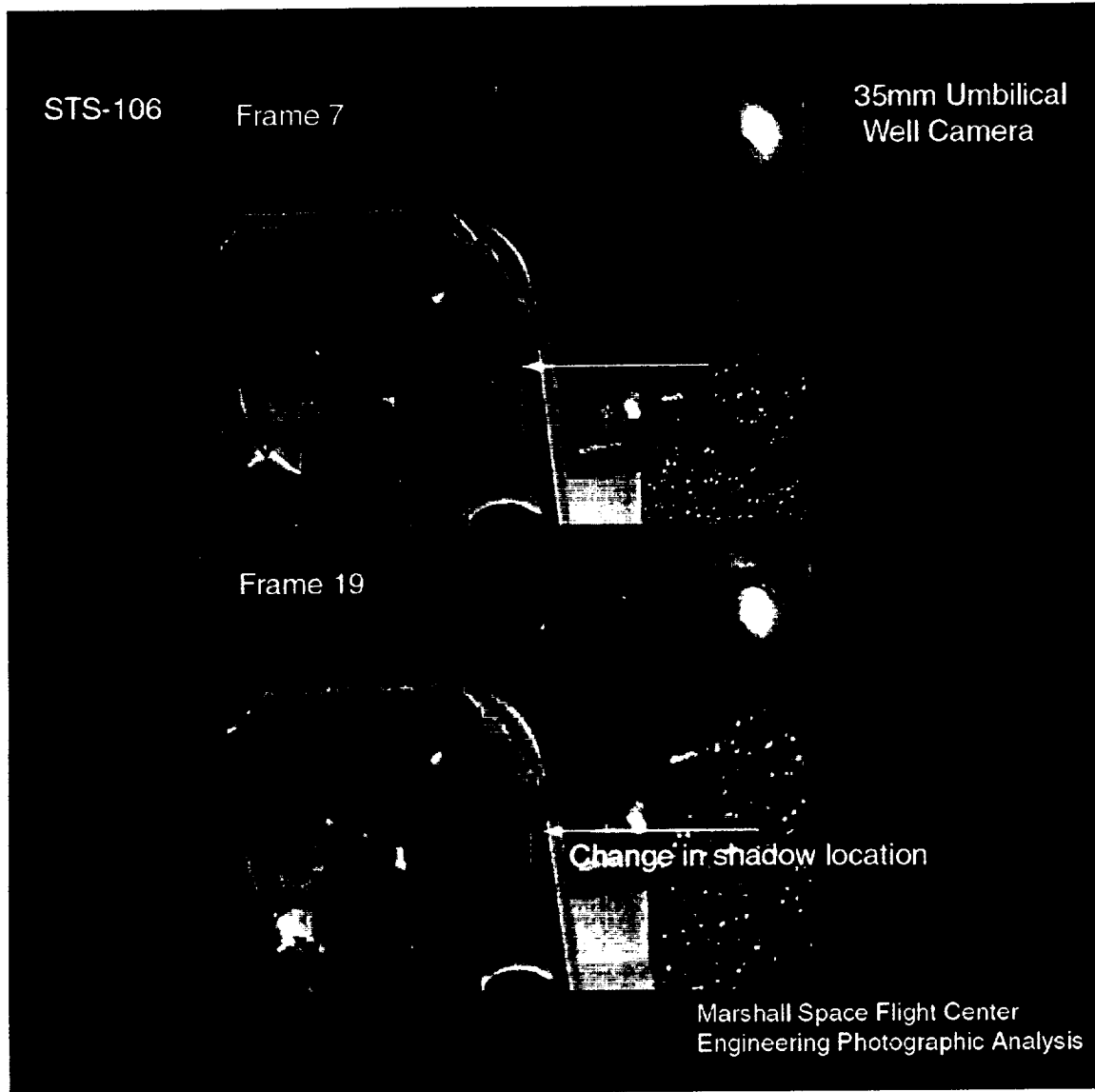
The sun may be assumed to be a point source of illumination at infinity and change of the shadow on the ET surface may be viewed as a change of position/orientation of the ET without reference to the Orbiter orientation. In an effort to determine if the separation bolt was moving, shadows from fixed positions on the ET were investigated at two different times.

Four observations were made by comparing frames 7 and 19 of Figure 20.

- Changes in image size implying a growing distance between the Orbiter and ET.
- No rotation in the orientation in the XY plane.
- A positional shift in the +X direction between the ET and Orbiter.
- A small rolling or pitching motion of the ET.

The positional shift in the +X direction is consistent with the +X translation performed by the Orbiter after ET separation.

Comparing figure 19 and 20 indicates that shadow changes from fixed points on the ET are consistent with shadow changes on the EO-3 separation bolt and no motion of the bolt is evident.



**Figure 18. EO-3 Fitting Bolt Shadow**

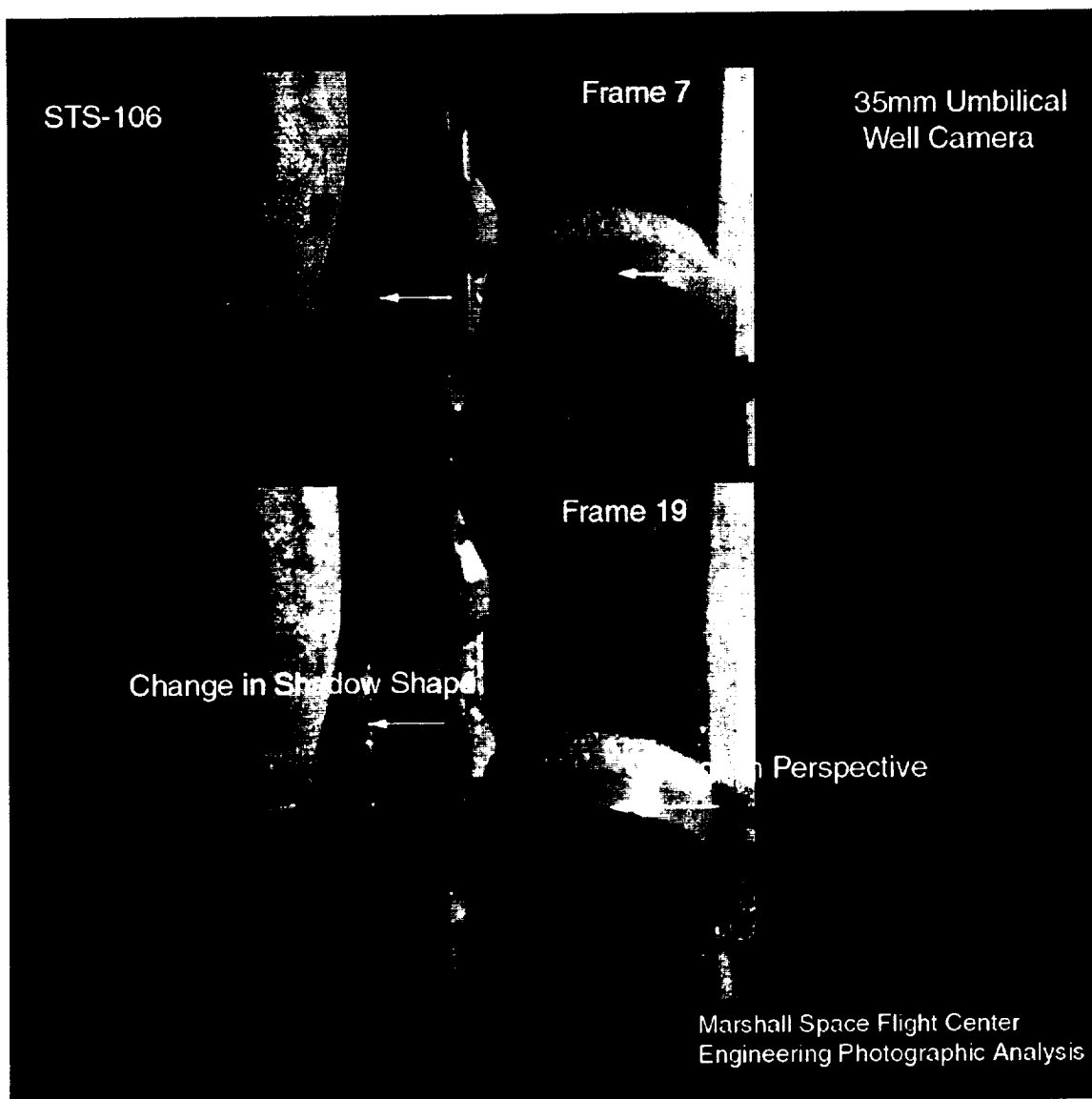


Figure 19. External Tank Motion Evidence

### 7.3 EO-3 Interface Fitting Historical Imagery

The EO-3 interface fitting bolt has been observed to protrude from the fitting bore since early missions. Pictures were obtained from Lee Foster (TD50/MSFC) that show bolt protrusion on missions STS-2 and STS-7.



**Figure 20. STS-2 EO-3 Interface Fitting Bolt Protrusion**



**Figure 21. STS-7 EO-3 Interface Fitting Bolt Protrusion**

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# REPORT DOCUMENTATION PAGE

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